Report prepared for

Department of Indian Affairs & Northern Development

The Northern Economic Development Branch

by Warnock Hersey International Limited
Professional Services Division

Arctic Transportation Study

While this research report was commissioned by and prepared for the Government of Canada the views and conclusions expressed herein do not necessarily concur with those of the Government of Canada

ARCTIC TRANSPORTATION STUDY

A report prepared for

DEPARTMENT OF INDIAN AFFAIRS AND NORTHERN DEVELOPMENT

The Northern Economic Development Branch

by the

Economic Services Department

of

WARNOCK HERSEY INTERNATIONAL LIMITED

PROFESSIONAL SERVICES DIVISION

Table of contents

TABLF OF CONTENTS

./.

TABLE OF CONTENTS

Introduction

INTRODUCTION

In recent years, there has been a rapid increase in the rate of exploration for minerals in Canada's Arctic Region*. In support of this activity, various modes of transport have been utilized to move men and materials into remote areas under conditions of extreme cold, rugged terrain, permafrost and muskeg. This surge of exploration activity has served to add to the extent of the knowledge of previously indentified resources of the region. Additionally it has provided information regarding the potentials that exist for the discovery of substantial quantities of minerals, particularly, of oil and gas.

The exploration and development of mineral resources of Canada's Arctic Region will depend, to a great extent, upon transportation - the transportation of ore and metals, oil and gas from the remote areas of the North to world markets. The purpose of this study is to examine the existing modes by which commodities, that would be shipped in bulk, may be transported. Also, order of magnitude costs have been developed, from the best available data, for each mode of transport.

./.

* For the purpose of this study the Arctic Regions include that area of Canada, north of the 60th parallel.

Introduction . / .

The terms of reference provided for the Arctic Transportation Study are as follows:

Terms of Reference:

a) Evaluate the transportation modes now in use in the Canadian Arctic and the volume of bulk commodities moving from there to national and international markets.

b) Analyse all available information and materials respecting climatic, geographic, hydrographic or other constraints which affect the adapation of high volume transportation modes to conditions in the Canadian Arctic.

c) Determine what transportation modes will, during a period to be agreed upon by the parties, encourage the maximum development of the resources of the Canadian Arctic and permit the maximum volume of bulk commodities to be moved from there to national and international markets: and

d) Estimate the total capital and operating costs of adapting to Canadian Arctic conditions each of the transportation modes considered in this study, including the capital and operating cost of any land terminal installations and harbour sites required.

e) Recommend terms of reference for such further investigation of Canadian Arctic transportation problems as may appear from the study to be desirable.

Several progress meetings were held as the study was being prepared. It was understood that the paragraph in the original terms of reference relating to economic benefits be ignored and that information on the following items, not provided for in the original Terms of Reference, be added:

1. Navigational aids.
2. First order of magnitude costs for the various modes on a ton-mile basis.
3. The Alexbow principle.

Terms of Reference ./.

The consultants wish to acknowledge the cooperation extended by the many people contacted during the course of this study, and, in particular, officials of Departments of the Federal Government. Numerous reports, charts and maps, both published and confidential, were made available to the project team.

Summary

SUMMARY

The Arctic Transportation Study examines various possible modes by which bulk commodities may be transported under conditions imposed by the Arctic Region. The modes of transport examined include surface ocean vessel, submarines, pipelines, railways, air cushion vehicles, aircraft, off-highway vehicles, conveyor belts, and monorails.

Surface ocean vessels, nuclear submarine supertankers, unit train railway and pipelines are the four modes of transport deemed most economical to transport commodities in bulk from the Canadian Arctic Region to national and international markets.

Surface ocean vessels of the type known as dual purpose bulk carriers (bulk/oil), are the most economic means of delivering oil and bulk commodities to the Eastern United States and Europe. The economic factors, as presented within this report, indicate that, on a cost per ton-mile basis, this mode of transport is less expensive than either submarine supertankers, railways or pipelines. The S. S. 'Manhattan" project is a major factor in the evaluation of the technical feasibility of dual purpose bulk carriers.

Summary ./.

The submarine, powered by nuclear energy, has proven itself capable of reconnaissance in the Arctic. The success of a nuclear powered submarine supertanker would appear certain from a technological point of view. Economically, ton-mile costs of nuclear submarine supertankers would be higher than a surface ocean vessel. In both cases, it is assumed that the vessels would be constructed in the U.S.., where shipbuilding costs are high. Also in both cases, a year round operation is assumed. If, as a result of the S.S. "Manhattan" experiment, it becomes apparent that 12 month surface navigation is impractical, then the nuclear submarine supertanker could become an attractive alternative. Unfortunately, world shipyards are not presently equipped to construct a nuclear submarine supertanker.

Pipelines, as a mode of transport, present technical problems associated with construction, as well as operation, in the Arctic. These problems include construction and operation in permafrost, which could prove costly to overcome. Additionally, such factors as the size of reserves present unkowns, that could significantly affect the cost of transporting oil by pipeline, as the potential economies of this mode are achieved when daily crude oil throughputs are high. At present, a

Summary ./.

major study is being undertaken to determine the feasibility of constructing a pipeline from the North Slope of Alaska to Edmonton. Concurrently, plans are advancing for the construction of the Trans Alaska Pipeline from Prudhoe Bay to Valdez.

If large volumes of materials are to be transported overland, then a unit train operation is most economical. The economics of the unit train and its known operating characteristics in northern regions favour it over a monorail system which has neither proven itself as an ore carrier nor a transportation mode capable of operating efficiently in the Arctic.

Both monorail and railway require large initial capital outlays which must be written off over the life of the reserve being depleted and, therefore, require high volume operation to be economically justified.

Transportation of products such as iron ore, copper concentrate, and sulphur over relatively short distances in the Arctic, for instance, from a mine to a marine terminal, can be carried out by off-highway vehicles, railway, conveyor belt, monorail or air cushion vehicles (ACV's). The rate at which the product is to be shipped, the

topography and the capital and operating costs combine to determine which of these modes is most economical for a given situation.

When large tonnages and short distances (under 5 miles) are involved, belt conveyors become an economically and technically feasible alternative. The physical constraints placed on the operation of a railway over relatively short distances increase operating costs substantially.

Off-highway trucks operate effectively and economically when low annual tonnages are involved, and the cost of operation of ice roads travelled by such vehicles decreases with frequency of use.

Air freighting is costly at present, and even for "jumbo" transports, the unit cost of air transportation will still be greater than all other modes of transport considered in this report, except air cushion vehicles (ACV'S) and monorail. However, when such factors as storage costs and travel time are considered in an integrated transportation system, air freighting may prove a viable alternative for some commodities.

Summary ./.

The map entitled "Transportation Modes and Costs" records first order of magnitude costs in the transporting of hypothetical and actual resources to market. Costs for the more obvious modes of transport are developed; except where noted by an asterisk, these costs are exclusive of profit, insurance and contingencies.

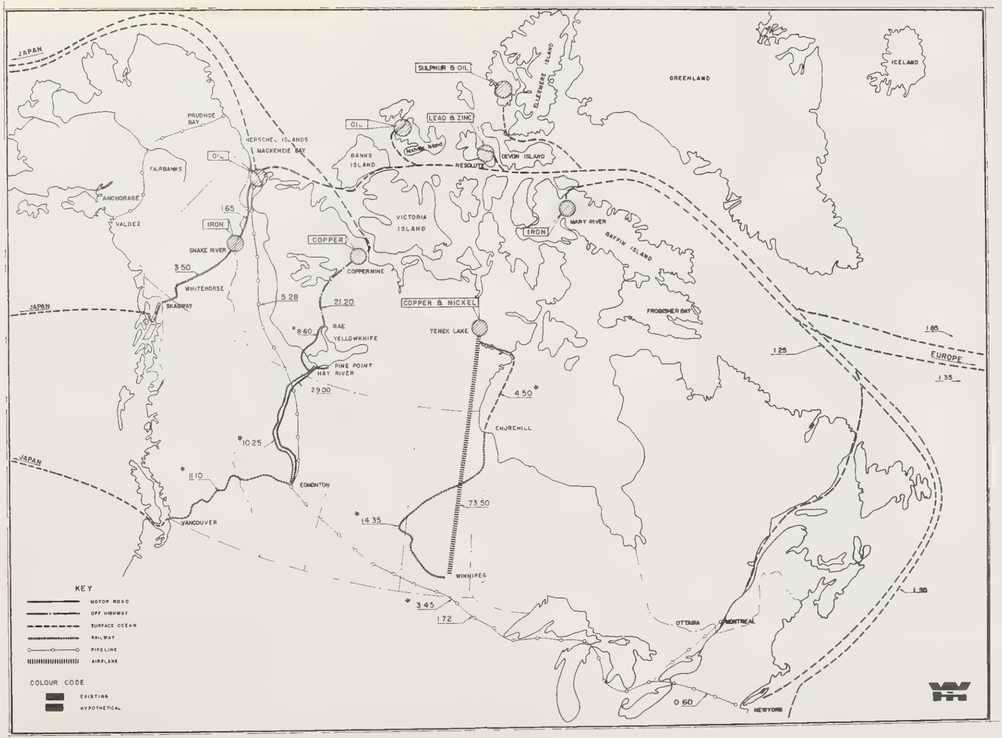
As an example, the hypothetical oil reserves at Mackenzie Bay can be moved to the Eastern U.S. by two means: surface ocean vessels and pipeline. As no commercial ocean service exists between Mackenzie Bay and the U.S.east coast, the proposed route is indicated in red. First order of magnitude costs, exclusive of profits and insurance, amount to $1.95 per ton.

To move the oil by pipeline would cost $5.28 per ton from Mackenzie Bay to Edmonton, plus $1.72 from Edmonton to Buffalo, plus 60¢ from Buffalo to New York, for a total of $7.60 per ton. As in the case with the costs developed for surface ocean transport, the figures are exclusive of profit and insurance.

It is apparent that on the basis of first order of magnitude costs, oil can be more economically transported from Mackenzie Bay to the U.S. East Coast by bulk carrier than by pipeline.

TRANSPORTATION MODES AND COSTS ($/TON)

(EXCEPT WHERE NOTED BY * COSTS ARE EXCLUSIVE OF PROFIT AND INSURANCE)



Resources of the Canadian Arctic

RESOURCES OF THE CANADIAN ARCTIC

Canada's Arctic Region is considered to contain substantial oil and mineral resources. The oil potential north of the 60th parallel has been estimated, by a number of experts, to be as high as 300 billion barrels. Sverdrup Basin, in the Arctic Archipelago, likely contains the world's largest reserves of native sulphur. High grade iron ore deposits, of extensive magnitude, have been discovered in north-west Baffin Island. These are but examples of the large scale resources which are known to exist in the Arctic region. Indeed, much of the Arctic's non-renewable resources are not presently being exploited.

Specified Reserves in Selected Areas

The following table sets out estimates of production and reserves of oil and minerals in selected areas of the Arctic. The table has been developed solely for purposes of this report and the figures are only approximations. In some cases they are purely hypothetical.

TABLE OF SPECIFIED RESERVES IN SELECTED AREAS*

IRON:	Reserves (short tons)	Production per year (short tons)	Life of reserves (years)
Snake River	20 billion tons ore	5-10 million tons concentrate	greater than 50
Baffin Island Mary River	130 million tons ore	4 million tons ore	greater than 30
COPPER:			
Coppermine	4 million tons ore	20 thousand tons concentrate	10
LEAD & ZINC:			
Little Cornwallis Island	40 million tons ore	300 thousand tons concentrate	14
SULPHUR:			
Axel Heiberg Island	10 million tons ore	500 thousand tons	20
COPPER - NICKEL:			
Tehek Lake	25 million tons ore	65 thousand tons metal, or 500 thousand tons concentrate	13

OIL & GAS	Oil(bbls)	Gas (Cu. Ft.)	Oil (bbls)	Gas (Cu. Ft)	Life of Reserves
Mackenzie Bay	2 billion	12 trillion	80 million	480 billion	25
Northern Melville Island	500 million	3 trillion	20 million	120 billion	25
Axel Heiberg	500 million	3 trillion	20 million	120 billion	25

* Figures are only approximation, and, in some cases, hypothetical.

MARKET

Oil

The marketability of Canadian Arctic oil will depend heavily upon the transportation modes and the total transportation system which will be developed in order to deliver the necessary quantities of crude oil at competitive prices to world markets.

Potential markets would include Western Europe, Central and Eastern Canada, the U.S. East coast and the U.S. Midwest.

Countries as far away as Japan could be potential buyers depending upon the economics of transporting oil and the well head price in the Arctic.

Gas

The U.S. reliance upon Canada as a major supplier of natural gas requirements has been steadily increasing over the years. The American need to buy Canadian gas will continue to grow and provide a substantial market for potential Canadian Arctic Gas.

Gas ./.

Transportation developments will again play a major role in opening up markets for natural gas and liquefied petroleum gas (LPG) products.

Canadian gas reserves and the anticipated American demand for gas may place Canada in a more favourable bargaining position to sell more oil to the U.S.

Base Metals and Minerals:

The United States, Western Europe and Japan would probably be the largest potential markets for base metals and minerals from Canada's Arctic Region.

Constraints to transportation in the Canadian Arctic

CONSTRAINTS TO TRANSPORTATION IN THE CANADIAN ARCTIC

METEOROLOGY

Meteorological data is presented in Appendix 1 for six observation stations in the Arctic. The stations include Aklavik, in the Mackenzie Delta, Coppermine on the west end of Coronation Gulf, Mould Bay on the north side of McClure Strait, Resolute on the north side of Barrow Strait, Resolution Island in the entrance to Hudson Strait and Nottingham Island at the entrance to Hudson Bay.

As indicated on the charts, temperatures remain above freezing for only a short period in the northern Arctic, from mid-June to mid-August and extend for an additional two to three week period in the southern Arctic. In the summer period, average temperatures vary between 40 and 55 degrees Farenheit, whereas during winter, temperatures fall to 20 or 30 degrees Farenheit below zero.

A general wind pattern resulting from low and high pressure can be defined over most of the Arctic. At Aklavik, Resolute and Mould Bay, winds usually blow from the north to north-west and south to south-east during the winter period. Conditions are more variable during the summer months when the winds shift to east and west because of unsettled atmospheric

Meteorology ./.

At Coppermine, Resolution and Nottingham Islands, south-west, west and northwest winds prevail during the winter, usually shifting to the north and east during the summer.

Calm conditions prevail during the winter months for as much as 10 to 35 percent of the time at Coppermine, Mould Bay and Resolute, and in the summer, only 5 to 10 percent of the time. Nottingham and Resolution Islands have calm winds a mere 2 to 5 percent of the time during both summer and winter.

Gale winds are most common for Resulution Island with up to five days per month of gale conditions occurring during winter and one or two days per month during the summer. Mould Bay has gales usually one day per month throughout the year. Most other observation stations record gale conditions during February, March and April.

Fog conditions are more prevalent during the summer and are most severe at Nottingham and Resolution Islands. These islands experience ten to eighteen days of fog per month, particularly from June to September. Aklavik records one to two days

of fog per month during September, October and November, whereas Coppermine and Mould Bay report fog throughout most of the year, with the maximum density and frequency occuring during August and September.

In general, overcast skies occur between 30 and 60 percent of the time during the winter months and increase to a maximum of 60 to 80 percent during late summer.[1] Clear skies occur 40 to 50 percent of the time during the winter months and 10 to 30 percent of the time during the summer.[2] Resolution Island is the most fog-bound and overcast of all the observation stations with clear skies occuring only ten to twenty percent of the time throughout the year.

GEOGRAPHY

Physiography

The physiography of the Canadian Arctic, to a large extent, reflects the contours of the underlying bedrock rock type and structures. Only at locations where accumulations of deep glacial deposits exist is the topography to a lesser degree influenced by the bedrock. General physiographic conditions are shown in Appendix 11.

. /.

(1) Overcast skies are defined as more than eight-tenths covered; blowing snow is a factor in producing overcast conditions in the Arctic.
(2) Clear Skies are defined as less than two-tenths covered.

Physiography ./.

Rock of Precambrian age comprises the high rugged and barren landscape along the eastern coast of Baffin, Devon and Ellesmere Islands, as well as along most of the northern coastline of the District of Keewatin.

Horizontal, Paleozoic sedimentary rock formations are relatively thick and low-lying in the southern Arctic and form the Paleozoic Lowlands. To the north, the formations are thicker and form plateaus up to about elevation 2000'. Further north, the sedimentary rock outcrop formations on the Arctic islands have been highly folded and form the Innuitian region.

Flat-lying, still younger mesozoic and Tertiary sedimentary rocks occupy the lowlands on the west coast of the Arctic islands including Banks, Prince Patrick, Sverdrup and Axel Heiberg.

Permafrost:

Long periods of freezing temperatures in the Arctic result in a condition where the degree-days of frost are greater than the degree-days of thawing. Permafrost (soil or rock whose temperature remains below 32^{o} Farenheit resulting in permanently frozen ground) is a direct result of this imbalance.

Permafrost ./.

The problems associated with construction in permafrost zones are numerous. Work carried out in these regions tends to alter the surface insulation properties and disrupt the thermal balance. The resultant lowering of the permafrost table by melting and thawing of the frozen ground is the cause of many construction problems in the Arctic.

Frozen soil provides a strong and firm base for any type of structure, however it may, when thawed, lose its strength to such a degree that it will become practically semi-liquid and unable to support the weight of a man. Melting of ice segregations in the soil results in large settlements of the ground surface during summer, whereas the formation of ice lenses during the freezing period can cause the surface of the ground to heave and be displaced several feet.

An additional, and even more severe problem with permanently frozen ground, is that it impedes the customary vertical drainage of water that results from the melting of surface snow and ice. Precipitation and melt water must therefore flow along the surface of the ground towards the nearest drainage channel. Such a flow of water, together with steep gradients, results in serious erosion of the finer soil particles.

Permafrost ./.

Permafrost problems are more acute where finer grained soils are encountered since such soils contain up to 60 percent ice by volume. Apart from the erosion problem which is so frequently experienced, settlement by as much as six feet in ten can be experienced when such soils thaw.

Disturbing the insulation properties of the surface layer must be avoided wherever possible. Granular fills placed on existing ground surface during construction cause the permafrost table to rise into the fills, thus eliminating any disturbance of the insulation layer while also stabilizing the fills. As an alternative, structures can be supported above ground on piles or piers which eliminate the thawing effect of buildings.

HYDROGRAPHY

Tides, Currents and Water Depths

The charts in Appendix 111 indicate the tides, currents and water depths in the Canadian Arctic.

Tidal fluctuations vary considerably across northern Canada being less than two feet in the Arctic Ocean and Mackenzie Bay but increasing to about forty feet in Ungava Bay in northern Quebec.

Tides, Currents and Water Depths ./.

Surface currents in the Beaufort Sea are clockwise at about 1.2 knots, while currents in Baffin Bay and Davis Strait are counter-clockwise at about 0.1 knots. Within the Arctic Islands proper, easterly currents reach a maximum of 7 knots in the Bellot Strait between Somerset Island and the Boothia Peninsula.

The greatest depth of water has been found beneath the Polar ice pack where depths vary between 200 and 600 fathoms, reaching a maximum of about 1000 fathoms. In Hudson Strait, between 100 and 200 fathoms of water may be found extending as far west as Southampton Island. In Hudson Bay proper, 100 fathoms of water is found in the Central part, the depth decreasing gradually as the shoreline is approached.

The few soundings available in the Northwest Passage indicate depths of between 100 and 300 fathoms with the exception of the western end of Barrow Strait, and north of Prince of Wales Island, where depths decrease to 35 and 60 fathoms. At the mouth of the Mackenzie River, shallow water (less than 10 fathoms) extends a distance of 10 to 15 miles offshore.

Ice Conditions

Information on the general ice conditions in the Arctic is

charted on a regular monthly and bi-monthly basis in Appendix IV. These charts indicate that all of the waters in the Canadian Arctic are ice-covered between October and May with sections of open water developing during the break-up period.

Areas of virtually no breakup include the Arctic Ocean where the "Pack " ice develops melt water puddles on the surface during summer. Sections of open water vary from year to year but in general include Hudson Bay and Strait, Lancaster Sound, Baffin Bay and Davis Strait in the eastern Arctic. In the western Arctic, breakup begins late in May along the Mackenzie Bay, Amundsen Gulf, Coronation and Queen Maud Gulfs and open water conditions exist during August and September, after which freeze-up begins.

During May, heavy ice moves southward from the Arctic pack into the entrance to McClure Strait. This movement continues until late July when the ice has moved completely down the Strait leaving only the Prince of Wales Strait relatively free of ice.

During middle or late September, temperatures drop to the freezing point and ice begins to accumulate in the protected bays and inlets of the northern islands, the same occuring a few weeks later in the Southern Arctic.

Ice Conditions ./.

As temperatures continue to decrease, ice forms along the shores and in quiet open water. Storms cause the shore ice to break-up and drift out into open water resulting in large packs of ice. This continues until the channels are completely frozen or filled with moving pack ice. By mid-November all the northern channels are covered with ice, but large areas of open water remain in Baffin Bay, David Strait, Hudson Bay and Hudson Strait.

By the end of November the ice is approximately two feet thick and continues to increase with time to about 6 or 8 feet in the bays and inlets. Ice-rafting, caused by winds and currents, results in thicknesses which may reach 20 to 30 feet in height. Along the coast, pressure ice may be lifted 40 feet or more above the surface of the water by onshore winds. Because of the difference in densities between ice and water, about one-quarter of the total thickness of ridged ice protrudes above sea level and as a result, a 20 foot high ice ridge may extend 50 to 100 feet above sea level.

Modes of transportation in the Canadian Arctic and estimated costs

INTRODUCTION

The section entitled "Modes of Transportation in the Canadian Arctic and Estimated Costs" evaluates existing and anticipated modes of transport. Estimated capital costs and operating costs are developed. Sample calculations of unit costs for each mode, based on specific volume and distance assumptions, are developed in Appendices VI to XIV.

All unit costs developed in the Appendices and recorded in Figures 4 and 5 are exclusive of profits, insurance and contingencies.

Unit transportation costs vary with distance and with volume. Figures 4 and 5 on Pages 85 and 88, relate unit costs to distance and quantities. Referring to Figure 4 and selecting railway as an example, unit costs in moving 500,000 tons annually over a 500 mile line would amount to 6.98 cents per ton-mile. By increasing annual tonnage to $2\frac{1}{2}$ million tons, unit costs would decline to 1.54¢. Ten million tons per year could be transported at a cost of .52¢ per ton-mile.

In Figure 5 annual tonnages are held constant (7.5 million tons for railway) and distance is varied. If the rail line were but 50 miles long unit costs would be .79¢ per ton-mile. If the line were 1000 miles long unit costs would fall to .63¢.

Introduction ./.

The constant distances selected in Figure 4 for each mode correspond to the movement of a particular resource, as recorded in "Resources in the Canadian Arctic" (page 13), to market or to another transportation mode. In the example of the railway, the resource is the iron ore deposit at Snake River and 500 miles is the approximate distance from Snake River to Skagway. Similarily, the fixed tonnages used in Figure 5 refer to the estimated annual production of the resource (page 14). In the case of the Snake River, $7\frac{1}{2}$ million tons of iron ore concentrate would be produced per year.

SURFACE OCEAN TRANSPORTATION

General:

Ocean transportation in the Arctic has been restricted, because of ice conditions, to the months of August, September and part of October, with slight variation in season from year to year. This variation results from the effect that wind and temperature have on ice break-up and decay in July and ice formation in October.

Supplies into the Arctic are, for the most part, carried by ship. Ice strengthened ships of the 2000 to 10,000 DWT class are usually employed, assisted by ice-breakers during the opening and closing of the navigation season.

Increased knowledge of Arctic ice, currents, bathymetry, and meteorology, together with improved design of ice-strengthened hulls for Arctic trade, has substantially increased the reliability of northern marine transport in recent years. However, the extent of navigational data available for ocean going vessels in the Arctic still falls far short of that which is available for the widely used and established trade routes of the oceans.

Not only must a great deal of additional navigational data be collected, catalogued and interpreted but further improvements must be made in the design of vessels if shipping is to be carried out on an

WARNOCK HERSEY INTERNATIONAL LIMITED
PROFESSIONAL SERVICES DIVISION

extended season basis in the region

extended season basis in this region.

S. S. "Manhattan"

In an effort to gather data and prove the feasibility of year round Arctic marine transportation, the S.S. "Manhattan", successfully traversed the Northwest Passage in September 1969, indicating that navigation in Arctic waters is operationally feasible for large vessels. The "Manhattan", before being strengthened and equipped for this voyage, had the following basic statistics:

Length overall	940' - 5"
Extreme breadth	132' - 6"
Maximum draft	50' - 0-1/2
Moulded depth	67' - 6"
Total shaft horsepower	43,000 (twin screw)
Service speed	17 - 1/2 knots
DWT	108,588

A special ice breaking bow and additional strengthening of the hull and machinery increased the weight of the vessel by 13,000 tons.

S. S. "Manhattan" ./.

During the voyage of the S.S. "Manhattan", aerial reconnaissance was provided by a specially fitted DC-4 carrying trained ice observers. Two helicopters supplemented the DC-4. However, at night and during poor flying weather, a vessel must place greater reliance on her own ice-sensing devices to detect difficult ice conditions that may lie ahead. The equipment aboard the "Manhattan" did not prove to be completely reliable and the vessel often found herself crashing through hard core ice without being previously made aware of it. Installation of more advanced detection equipment would probably overcome this problem.

The voyage confirmed that the basic hull design of the "Manhattan" is satisfactory. There is less certainty about the adequacy of her twin screw, 43,000 shaft horsepower, as she required ice breaker support on a number of occasions. Since power requirements will, in fact, be a function of the ice breaker support system, then the greater the power of the bulk carriers commercially travelling this route in the future, the less ice-breaker support that would be required. It is not inconceivable that a 250,000 DWT vessel may require 100,000 horsepower, triple that which is normal for a ship of this size. The geared steam turbines of the "Manhattan" were also slow to reverse which proved to be a considerable handicap when quickly moving ice surrounded the stern and made backing off difficult and, at times, impossible.

S. S. "Manhattan" ./.

Although the results of the S.S. "Manhattan" voyage have not been completely analyzed at this time, it may be concluded that the experiment did indicate that navigation in Arctic waters is operationally feasible in late summer and early fall. The economic viability of commercial navigation in this region, however still remains to be established. As a pilot study, the "Manhattan" has provided the direction which is necessary for similar experiments to take place in the future.

Ice-Breaking Alexbow

Conventional ice breakers use the principle of running the ship up onto the ice and, under the weight of the ship, the ice breaks; part being pushed aside and part passing under the ship in its forward travel. If the ice does not break under the weight of the ice breaker, rocking the ship may be necessary, or even backing off in order to take another run at the ice.

The Alexbow principle is based on a plow-shaped bow attached to an ice breaker. The plow projects in front of the ship below water level with a knife-like blade running along the leading edge of the plow. This blade makes contact with the soft under-surface of the ice causing a cleavage of the ice from the point of contact clear through to the top surface.

The principle is very sound indeed. In the winter of 1967 - 1968, the trials of an Alexbow fitted barge/tug in Lake Ontario proved that 16 inches of clear blue ice, containing no cracks or leads, and shorefast, could be broken. A clear channel, 34 feet in width resulted, just two feet wider than the barge's 32 foot beam.

In addition to the trials, a sealift of some 4000 tons was succesfully completed to Rea Point on Melville Island in the summer of 1968. The Learmonth, a 2000 ton dry cargo barge fitted with an Alexbow and the Scotty Gall, a 2000 ton tanker barge, were partly towed (through open water) and partly pushed (through ice and restricted channels) by the 4700 H.P. tug, Irving Birch. The Scotty Gall was left to winter at Rea Point and the Irving Birch, pushing the Learmonth, carried out limited tests in the ice off the coast of Melville Island.

It is felt that additional testing should be carried out and possible modifications made to Alexbow geometry resulting from these tests and through tank tests with models. The next step should then be integration of the Alexbow into the total design of a self-propelled ship of some considerable size, rather than the addition of the Alexbow to a barge. An intermediate step may be the refitting of an existing ship with an Alex bow and the up-grading of the ship's structure and machinery to ice breaker class. Cost appears to be the main reason for not carrying out this intermediary step. It is estimated that the cost of fitting and subsequently removing

an Alexbow from an existing ship would be in the order of $700,000 to $1,000,000.

Omega Navigation System

Omega is a VLF (very low frequency) navigation system which will provide worldwide coverage with only eight transmitting stations. Fix accuracies of one to two miles can be obtained under normal operating procedures. The use of differential Omega, which is a refinement of Omega, will provide fixes with errors of one-half mile or less. The latter system can be used for rendezvous with an accuracy of about two hundred yards.

For navigation in the Canadian Archipelago, recent tests conducted in the Arctic by Department of Transport indicate that the eight existing Omega transmitting stations appear sufficient to provide ships, aircraft and submerged submarines in the Arctic with a general purpose navigation system.

If it were eventually found that a ninth Omega transmitting station was necessary for navigation in the Arctic, the cost of such a station would be in the order of $15 million, with annual operating costs of about $1 million.

Omega Navigation System ./.

The cost of surface ship receivers can vary from $20,000 to $300,000 for a unit with computer tie-in to a ship's Inertial Navigation System.

Costs of dual purpose Oil/Dry Bulk Carriers

The construction costs of three classes of dual purpose oil/dry bulk carriers suitably strengthened and equipped for navigation through ice have been investigated. The vessels are of the following tonnages;

65,000 deadweight tons

150,000 deadweight tons

250,000 deadweight tons

Due to the severe ice conditions encountered in the Arctic, the standard of ice-strengthening is selected to meet Lloyd's Register of Shipping Ice Class 1 requirements.*

Previous navigation experience in the Arctic has indicated the necessity for above - average manoeuvrability on the part of vessels operating in these regions. This is because vessels must maintain full

* Lloyd's Register of Shipping Ice Class 1 requirements are recorded in Appendix V.

power and speed while penetrating through ice flows and must also be able to avoid very large pieces of ice which may have thicknesses greater than the draft of the vessels.

In view of this fact, provision has been made (in the analysis of capital costs) for twin-screw propulsion and bow thrusters on the vessels.

a) Additional weight and total costs for ice - strengthening - Class 1 *

The increase in light ship weight due to the requirements of Lloyd's Ice Class 1 have been estimated as follows:

Class of Dual Purpose Bulk Carrier	Additional Weight Required
65,000 DWT	540 long tons
150,000 DWT	775 long tons
250,000 DWT	970 long tons

b) Additional weight and cost of Twin-Screw Propulsion

./.

*Camat Transportation Consultants Inc of Montreal were commissioned to develop weight and cost information. Camat's Technical Report No. 28-158 summarized the firm's findings.

Costs of Dual Purpose Oil/Dry Bulk Carriers ./.

The three classes of vessels under review in this report, have, in the past, been designed and built for single-screw propulsion. The use of twin-screw propulsion may be advocated to enhance the manoeuvrability of these large vessels in Arctic waters. The S. S. "Manhattan" was originally built with twin-screws and, therefore, was a good choice for the the test passage to the North Slope of Alaska.

The increase in machinery weight for a twin-screw turbine propulsion plant over a single-screw propulsion plant for the three vessel sizes is as follows:

Class of dual Purpose Bulk Carrier	Additional Machinery Weight
65,000 DWT	470 long tons
150,000 DWT	475 long tons
250,000 DWT	480 long tons

The cost of machinery for the range of ship horsepower (S.H.P.)* under consideration presently varies between U.S. $1.25 and U.S. $1.50 per pound for equipment manufactured of ferrous material

* 20,700 SHP required for 65,000 DWT vessel; 25,000 SHP required for 150,000 DWT vessel; 33,000 SHP required for 250,000 DWT vessel.

c) Additional weight and total cost of Bow Thrusters[1]

The adoption of bow thrusters into the design of the vessels under consideration would further improve the manoeuvrability of the vessels. Thrust requirements vary with each size of vessel. By using empirical data, the amount of thrust required for each size of vessel has been calculated. The total cost of bow thruster installations on the vessels under review is as follows:

DWT	Capital Cost*	Installation Cost*	Total Cost*	Additional Weight
65,000	48,000	28,800	76,800	12.0 long tons
150,000	71,000	42,600	113,600	21.0 long tons
250,000	95,000	57,000	152,000	35.0 long tons

The deadweight capacity of each class of vessel will be reduced due to: the additional weight of steel required in order to ice-strengthen each vessel; the resultant addition of weight when a twin-screw turbine is ./.

* U.S. Dollars

1. A price of steel between U.S. $300 and U.S.$ 330 per long ton is used for the purpose of estimating the cost of ice-strengthening each of the vessel sizes.

Additional Weight and Total Cost of Bow Thrusters ./.

incorporated into the design instead of a single-screw and the incorporation of bow thrusters. Table 1 indicates the final capacity of each vessel.

TABLE 1

Final Deadweight Capacity of Oil/Dry Bulk Carriers

Type Vessel DWT	Vessel Capacity DWT	Ice Class 1 Deadweight Reduction	Twin-Screw Deadweight Reduction	Bow Thruster Dead-Weight	Final Capa-city DWT
65,000	69,830	540	470	12.0	68,808
150,000	150,000	775	475	21.0	148,729
250,000	250,000	970	480	35.0	248,515

Based upon the final vessel capacities developed in Table 1, the capital cost of each type vessel is indicated in Table 11.

TABLE 11

Final Capital Cost of Oil/Dry Bulk Carriers (U.S.$)

Type Vessel	Vessel Cost	Ice Class 1 Cost	Twin-Screw Cost	Bow Thruster	Final Cost	Cost DWT*
65,000	9,000,000	175,000	1,400,000	76,800	10,651,800	154.80
150,000	13,750,000	240,000	1,500,000	113,600	15,603,600	104.91
250,000	22,000,000	300,000	1,600,000	152,000	24,052,000	96.78

* Final Capacity DWT developed in Table 1.

Operating Costs:

Table 111 indicates operating costs of the three classes of vessels under consideration and are exclusive of profits, insurance and contingencies.

TABLE 111

Annual operating costs of ice-strengthened oil/dry bulk carriers (based on 1969 costs and U.S. $)

Vessel Class	65,000 DWT	150,000DWT	250,000 DWT
Shaft, H.P.	20,700	25,000	33,000
Fuel Consumption LT/day	100	122	160
Fuel cost/long ton[1]	$14.00	$14.00	$14.00
Fuel cost/per day	$1400	$1710.	$2240.
Fuel cost/day in port	$140	$170	$225
Lube oil cost/year	$1000	$1200	$1600
Maintenance cost per year (average/steam plants)	$30,500	$32,200	$33,500
Special survey[2] (cost includes a day docking)	$50,000	$100,000	$150,000
Crew cost[3] /year	$180,000	$180,000	$180,000
Crew vacation cost per year[4]	$30,000	$30,000	$30,000
Crew return trip home cost per year	$12,000	$12,000	$12,000

1 Average cost, includes volume discounts but does not include taxes
2 A special survey is carried out every four years.
3 Based on European crew of 30. This cost varies with degree of automation and origin of the crew.
4 Based on sixty days.

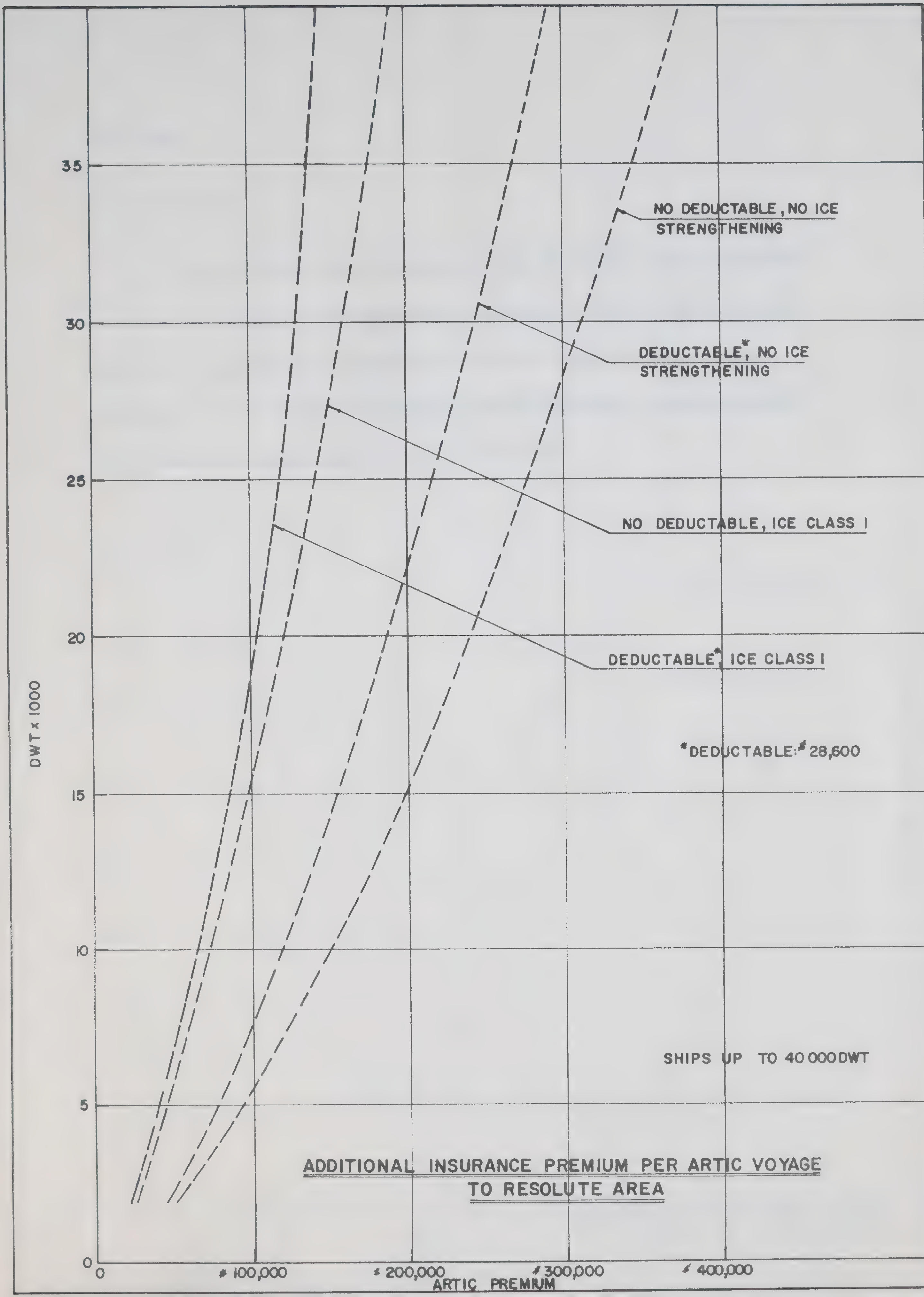
Insurance:

In addition to the usual marine insurance carried on a vessel, ships travelling north of 60° N. latitude must also pay an Arctic premium. This premium provides insurance only during the "normal" shipping period (July 23 to October 10) in the North, and is in addition to regular marine insurance which the shipowner would carry on his vessel.

Figure 1 records the additional insurance premium per Arctic voyage to the Resolute area for ships of less than 40,000 DWT. The four lines relate the Arctic premium to deadweight tonnages for four combinations of ice-strengthening and deductibility. The lines in Figure 1 are based on current rates. Coverage under the usual Arctic premium is restricted to vessels that do not cross 60° North latitude before July 23. The return voyage must leave Resolute by Sept. 15

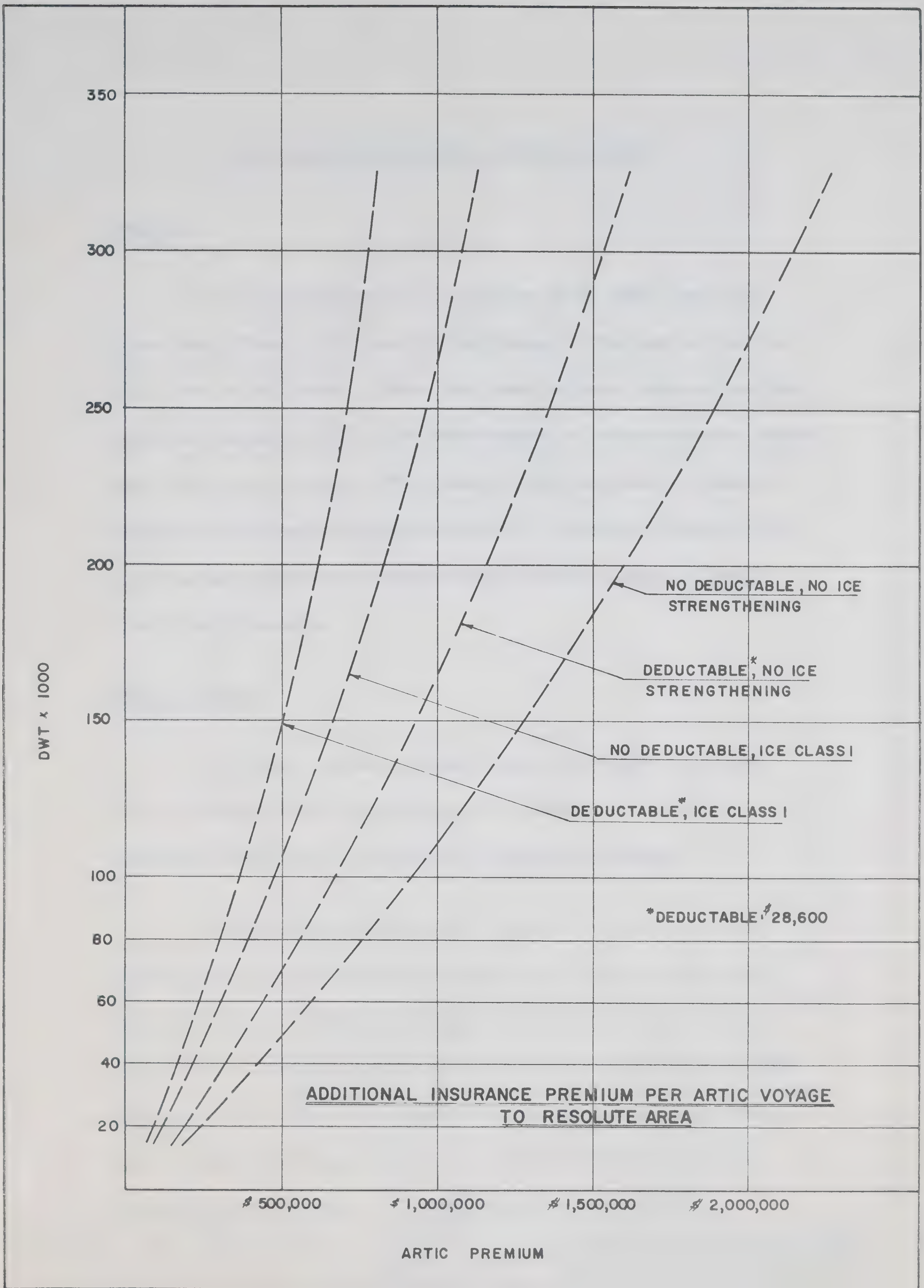
Arctic premiums are increased for vessels sailing outside the "normal" shipping season, as well as for additional ports of call. If a ship proceeds further north and/or west of Resolute, additional premium costs are incurred.

With few exceptions the Arctic experience of hull underwriters at Lloyd's is limited to the insuring of vessels of less than 150,000 DWT for voyages during the "normal" shipping season. Figure 2 depicts estimated Arctic premiums for vessels up to 325,000 DWT. The trend lines have been developed by recording actual Arctic premiums and


35
30
25
20
15
10
5
0
DWT x 1000
0
100,000
200,000
300,000
400,000
ARTIC PREMIUM
NO DEDUCTABLE, NO ICE STRENGTHENING
DEDUCTABLE*, NO ICE STRENGTHENING
NO DEDUCTABLE, ICE CLASS I
DEDUCTABLE*, ICE CLASS I
*DEDUCTABLE: # 28,600
SHIPS UP TO 40 000 DWT
ADDITIONAL INSURANCE PREMIUM PER ARTIC VOYAGE TO RESOLUTE AREA

extrapolating.

At the outset, the insuring of 150,000 DWT to 250,000 DWT vessels for 12 months navigation in the Arctic would be an extremely expensive proposition. Hopefully, a series of successful voyages, combined with a strong presentation to the insurers, would succeed in dramatically reducing insurance premiums.



ADDITIONAL INSURANCE PREMIUM PER ARTIC VOYAGE TO RESOLUTE AREA

NUCLEAR SUBMARINE SUPERTANKER

General:

The successful under-ice voyage of the USS "Nautilus" to the North Pole in 1957 was the beginning of frequent submarine operations in the Arctic. Since that time military submarines have played an important role in the development of submarine sea routes under the Arctic ice-cap. The Electric Boat Division of General Dynamics Corporation has researched the commercial operation of a submarine supertanker in this region and has concluded that it is technically feasible.

Basic Criteria:

A nuclear submarine supertanker could load crude oil in the Canadian Arctic and deliver it to markets on the North American East Coast by way of the Northwest Passage.

It has been estimated that a speed of 17 knots could be maintained for all but the terminal areas and a section through Barrow Strait where the water depth is limited to about 300 feet in one area. Normal cruising depth would be betwwen 300 and 400 feet below the surface. Where large icebergs are present, this depth would be increased to between 500 and 600 feet in order to ensure safe operation. The hull would be designed for

Basic Criteria ./.

a maximum cruising depth of 1000 feet.

It is estimated that the nuclear submarine supertanker would have an unreplenished endurance of about 26,000 nautical miles at her design operating speed. Continuously submerged operation under the Arctic ice-cap, as well as a submerged loading operation, would be well within the capabilities of the nuclear supertanker.

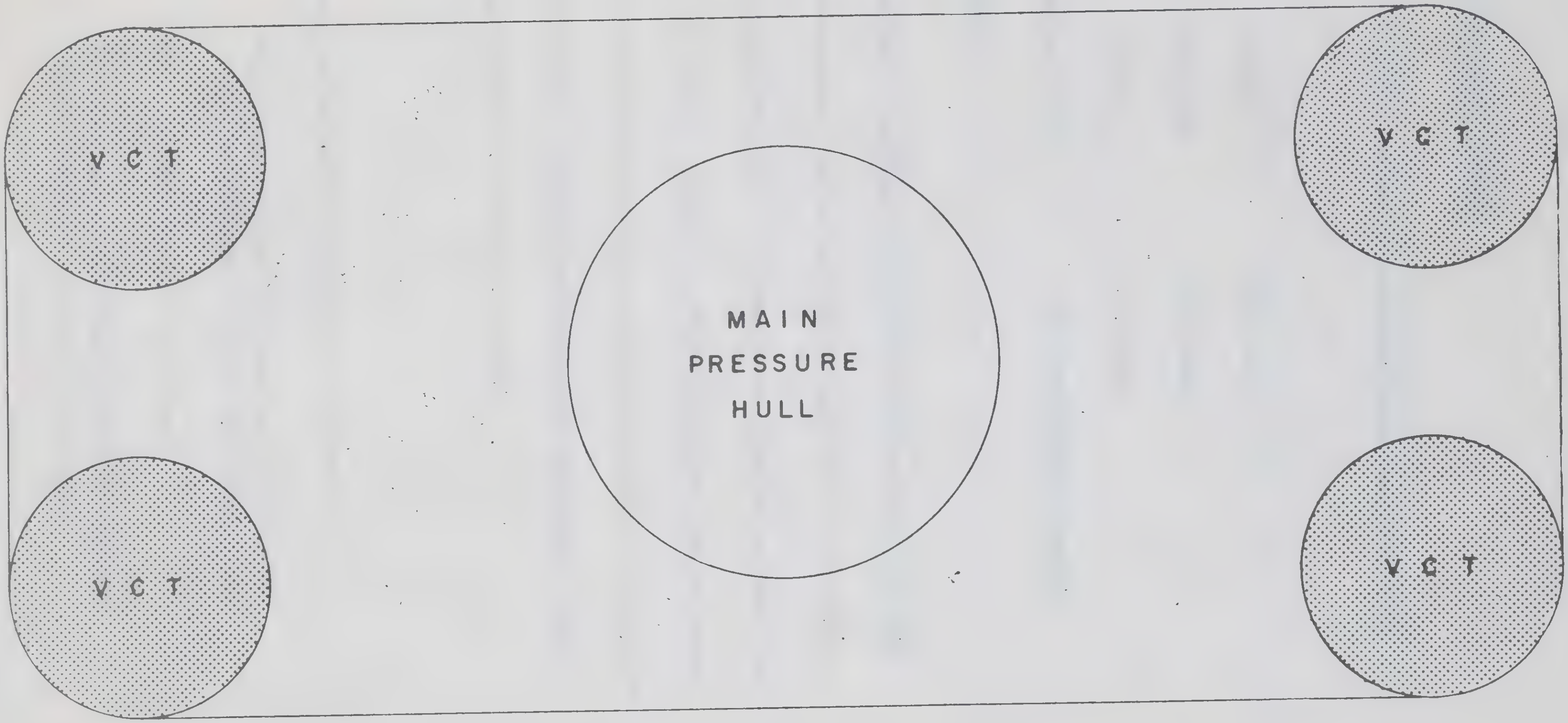
Basic Configuration and Design:

The hull cross-section of the submarine could be as outlined in the study dated March 1964 by Dr. H. E. Sheets of General Dynamics Corporation and as shown in Figure 3.

The main pressure hull would contain the propulsion unit and the living and working areas. It would be surrounded by an open tank (main cargo tank) containing the liquid cargo and bounded on the corners by trim tanks or variable cargo tanks (VCT), containing varying amounts of sea water or oil. This would permit adjustment of the overall weight of the vessel to equal the weight of the displaced sea water.

FIGURE 3

TYPICAL CROSS-SECTION OF A NUCLEAR SUBMARINE SUPERTANKER



Basic Configuration and Design ./.

A 250,000 DWT submarine would have the following dimensions:

Length	1000 feet
Breadth	180 feet
Depth	80 feet
Minimum Operating Draft	60 feet (approximate)

Navigation System:

The military inertial navigation system with its high capital and maintenance cost is not necessary for a submarine tanker. Eastablishment of a VLF radio navigation system such as OMEGA, in the Arctic, would provide position checks under the ice. Under-ice piloting would be accomplished by the use of forward-looking sonar to detect icebergs and pressure ridges, and upward echosounder to obtain ice draft.

Berthing:

Proposed underwater berthing is 3 phased:

a) navigation to the general vicinity of the docking are (10 to 20 miles away);

b) Approach to the dock; and

c) Mooring at a defined position with an accuracy to within a few feet.

Berthing ./.

Resolving the general ship position relative to the dock could be done by long-wave acoustic beacons. Once the initial position has been determined, the ship would enter into a docking approach pattern.

The docking portal could be marked acoustically by a pair of transponders, providing bearing information of increasing accuracy as the range to them decreases. When the ship is between the transponders, it would be on the centre line of the approach track, but still 2 to 3 miles from final destination.

A corridor of decreasing width magnetic fields could guide the submarine to the berthing platform. A second pair of transponders on either side of the berthing platform, midway along its length, could guide the ship close to final position over the platform. High intensity lights on the platform and television on the submarine would be used in final positioning.

The berthing platform would consist of a series of concrete boxes placed side by side in rows on the ocean floor to form a pad to accommodate the submarine. This system would appear to have many advantages over mono-mooring, underwater dolphins, or the catch-wire system.

Loading System:

Two pipes, one for oil and one for ballast water, would run the length of the berthing platform. The loading of oil would take place at not less than 16,000 tons per hour to enable a turnaround time of 24 hours.

Costs of Submarine Supertankers:

As noted in the section on surface ocean transport, there are difficulties in forecasting costs for the operation of large bulk carriers in the Arctic, in spite of the existence and operation of similar sized ships in more temperate waters. In forecasting costs for nuclear submarine supertankers which do not presently exist on a commercial basis, there is a considerable possibility of actual figures deviating from forecast.

Costs have been developed for the following sizes of submarine supertankers:

150,000 deadweight tons

200,000 deadweight tons

250,000 deadweight tons

The acquisition cost for each size submarine supertanker would vary with the size of nuclear propulsion plant installed.

Cost of Submarine Supertankers ./.

The size of plant would affect speed and efficiency of operation. Based upon current information and nuclear propulsion plants of optimal size, the acquisition costs are estimated for the tankers of the following sizes:

Size of Submarine Supertankers	Acquisition Cost (U.S. $)
150,000 DWT	85Million
200,000 DWT	110Million
250,000 DWT	135Million

Operating Costs :

Crew, maintenance, repair, stores and miscellaneous costs would amount to U.S. $1,195,000 annually. Variations in these costs for the three sizes of submarine would be negligible. There would be a variation in fuel costs, resulting in operating costs for the 250,000 DWT submarine being close to 25% higher than those for a 150,000 DWT submarine.

Operating, amortization and interest costs, by vessel size, are presented in Appendix V11 . These costs are based on the assumption of a 5250 mile distance between origin and destination, equivalent to the distance from Mackenzie Bay to the U.S. East Coast. As in the case of dual purpose bulk carriers, these costs exclude

some expenditures that are extremely difficult to predict with any degree of accuracy, namely insurance and profits.

A submarine, because it would travel beneath the ice, is less liable to ice damage and immobilization than a bulk carrier. Hence increases in cost due to ice damage and reductions in revenue because of immobilization would occur infrequently in the operation of submarine supertankers.

Capital costs would most probably be subject to upward revision. There is a parallel in the construction of nuclear submarine supertankers and the " Concorde " supersonic aircraft. In both cases, a military developed concept is adapted to commercial use in a vehicle of considerably larger dimension than the military version. In the case of the "Concorde", development costs have exceeded forecast by 300 -400%. Rarely are technological changes introduced at the forecasted cost. In summary, the probability of submarine supertankers being produced at the cost presently suggested is somewhat speculative.

PIPELINES

Long distance overland movement of gases, liquids and solids can be handled by pipeline, but experience in the construction and operation of pipelines in the Arctic is minimal. The logistics would be more demanding than in the south. The movement of thousands of tons of pipe into areas where roads do not presently exist would be an expensive proposition. If the line were to closely follow a major river, such as the Mackenzie, barges could be used in the summer. Otherwise, winter roads would be the main artery of transport. The route of the pipeline should be selected to minimize the length of the line, yet avoid the hazards of muskeg and soils with high ice content.

The construction season would probably be limited to a few months in late winter when temperatures are less extreme, daylight hours longer and the frozen ground capable of supporting heavy vehicles.

Whether the pipe is laid in the ground, on the ground or suspended above the ground, additional costs would be incurred in relation to construction costs in the south. Burying a 48" line would require a trench about 8 feet deep - a difficult and expensive task to undertake in permafrost.

Pipelines ./.

If the line were laid on the surface it would be subject to wide thermal variations. In the case of crude oil and slurry, unless the pipeline were insulated and heated, the extreme winter cold could reduce temperatures of the oil or slurry to the point where it would be difficult to pump. A buried line would not be subject to the temperature extremes of a surface line because of the insulation properties of permafrost and its overlay.

The suspending of a pipeline above ground would subject the exposed pipeline to temperature extremes. As in the case of laying the pipeline on the ground, insulation and heating of the line would be required to enable easy pumping. A suspended line would also incur the cost of construction of supports. As a 48 inch oil pipeline would contain 35 tons of oil per hundred feet, supports would have to be frequent to accommodate the weight of the oil and of the pipe.

The operation of a large diameter pipeline in the Arctic would result in high maintenance and fuels costs. Maintenance costs would be high because of the necessity of flying in men and supplies to service and repair pumping stations.

Oil Pipeline

The problems of constructing and operating a large diameter crude oil pipeline in the Arctic are being researched by, among others, Trans Alaska Pipeline and Mackenzie Valley Pipe Line Reasearch Limited. The latter named firm is conducting a $1.5 million physical and economic feasibility study of a 48 inch pipeline from the North Slope of Alaska to Edmonton via the Mackenzie Valley.

The costs of constructing a crude oil pipeline in the Arctic would be dependent on the route selected and on whether the line is buried, laid on the surface, or suspended. The proposed 48 inch Trans Alaska Pipeline from Prudhoe to Valdez will cost an estimated $1 million per mile. In view of the ruggedness of the terrain to be crossed and the very high proportion of permafrost along the proposed route, this figure can be viewed as a maximum cost. It is estimated that a 42 inch line crossing less rugged terrain in the Arctic would cost $375,000 per mile.

Operating costs of crude oil pipelines in the Arctic would be higher than in the south. If the crude oil were to be pumped cold, then greater fuel costs would be incurred. On the other hand, if the oil were to be pumped hot, fuel costs would not be as great:

Oil Pipeline . /.

but added costs may be incurred in heating the crude oil if insulation is inadequate.

Unit costs for oil pipelines are recorded in Appendix VIII and IX.

Natural Gas Pipeline

The problems relating to the pipelining of natural gas in the Arctic would be less severe than those encountered in the pipelining of crude oil. Low temperature would have little effect on the flow of natural gas. If temperatures of the natural gas in the pipeline were below freezing, then the gas would have to be "dried" before it entered the line. As the temperature of the gas would generally approximate that of the ambient, the stability of the permafrost would not be threatened.

One problem, which could arise, is that the temperature of the gas generally increases to well over 100°F at each station on the line. If this were to threaten the stability of permafrost, the gas would have to be cooled at each station.

It has been estimated that the proposed 48 inch Mountain Pacific Pipeline from Prudhoe Bay to Kingsgate would cost $725,000 per mile. Operating costs would be high in the Arctic. However,

Natural Gas Pipeline ./.

in view of the increased capital costs incurred in the Arctic, the "2½% rule", often used in more temperate climates, would represent an approximation of direct operating costs. This would indicate that direct operating costs for a $725,000 per mile line would be 2½% of capital costs - $18,000 per mile.

Slurry Pipeline

Extensive research is presently being carried out to study the economic feasibility of the movement of products such as sulphur, potash and coal in a slurry with water, oil or other carrier fluid. The possibility of multiple solids pipelines is also being investigated. "The potential for employment of slurry pipelines is greatest where no well developed transportation facilities exist. Obviously, a slurry pipeline would usually be at a competitive disadvantage where there is an existing direct rail, highway or waterway connection".[1]

Slurry pipelines are most advantageous when the volumes are large and the distances quite long. Short hauls would, of course, increase the ton-mile cost substantially because of the loading and unloading facilities that must be provided whether the distance is short or long. If Long distances are to be achieved with slurry pipelining ./.

1 "Some aspects of Slurry Pipeline Economics & Application", E.J. Wasp, and W. L. J. Fallow, Bechtel Corporation.

it will be necessary to have the solid in the form of a non-settling suspension (a slurry in which the solids do not settle, or settle very slowly) in order to maintain reasonable power costs. The high power cost that would be encountered with a settling suspension(a slurry in which the particles are coarse and settle quickly, thus requiring turbulent conditions for transport) would limit the competitiveness of this type of slurry pipelining to short distances.

Costs have been developed for slurry pipelines over 50 miles in length, transporting minerals with a specific gravity (S.G.) of 2.7 and 4.9.[1]

Annual Tonnage (million tons)	Cost/ton Mi. 2.7 S.G. (cents)	Cost/ton Mi. 4.9 S.G. (cents)
2	0.60	0.52
3	0.50	0.42
4	0.42	0.35
5	0.36	0.32
6	0.34	0.30
7	0.32	0.28
8	0.30	0.25

./.

(1) These costs were developed by Wasp and Fallow for their report titled "Slurry Pipeline, Economics and Application", presented at the Fifth Annual Meeting, Canadian Transportation Research Forum, Toronto, Ontario.May 1969.

Slurry Pipelines ./.

Construction and operating costs in the Arctic would result in a considerable upward revision of the ton-mile costs listed above. Selection and availability of a carrier fluid would be important. Water, obviously, could not be used if temperatures in the line were to be below freezing.

Capsule Pipeline:

Research is presently being carried out by the Federal Government and the Alberta Research Council in capsule pipelining*. Water, liquid hydrocarbons and air have been used experimentally as carrier fluids. The spheres, or cylinders, range anywhere from 5-7 pipe diameters in length. Conventional pumps are normally used to maintain the pressure within the line and velocities of the capsules are between 3-6 feet/second. Bypass systems are required at the pump stations in order to bypass the capsule around the pump.

Even though the work being done is still in the embryonic stage, the results so far have been encouraging. Phase 1 of this research was a preliminary economic and technological feasibility study of capsule pipelining. This phase indicated that capsule pipelining was indeed viable and that the reasearch should be pursued.

*Capsules are formed of the solid to be transported and may have a cylindrical or spherical shape with a diameter amounting to about 85 -90% of the pipe diameter.

AIRCRAFT

General:

Air freighting operations in the Arctic presently consist mainly of supplying goods to the region rather than transporting resource materials from it. Approximately 20,000 tons of freight per year are presently being transported into the Arctic, using a variety of aircraft such as DC3's, Lockheed Hercules, Boeing 737's,Super Constellations and DC4's.

Flight delays and cancellations due to climatic conditions hinder air operations in the Arctic. However, increased use of jet and turbo-prop air freighters, improved runways, and instrument landing systems will combine to improve reliability of flying schedules.

Airfields

The type of airfields available will influence the selection of aircraft to be employed. The Boeing 737 twin-engined pure jet is certified for gravel runway operations as is the Lockheed turbo-prop Hercules. The Lockheed 500 Galaxy, a four-engined jet freighter scheduled for a commercial use in the mid '70's, will also be certified for gravel runways.

Airfields ./.

Runway length and surface quality greatly affect the maximum payload weight of any aircraft. The length of runways required for the Lockheed Hercules and for the Lockheed 500 Galaxy vary as illustrated below:

Aircraft	Condition	Field length required*
Hercules	take-off at maximum take-off gross weight (MTOGW) of 154,324 lbs.	6,020 feet
Hercules	landing at maximum landing weight (MLW) 130,000 lbs.	4,660 feet
500 Galaxy	take-off at maximum take-off gross weight 831,000 lbs.	10,250 feet
500 Galaxy	landing at maximum landing weight 665,000 lbs	7,170 feet

Communications and Navigation

Airfields in the Arctic region will have to be equipped with communication and navigation facilities of the same type and sensitivity provided at major airports, namely:

a) Suitable medium to long-range navigation systems such as DECCA, DECTRA, OMEGA, and LORAN ./.

*Reduction in maximum take-off gross weight or maximum landing will reduce the field length requirement. Landing and take-off information were derived from manufacturers publications.

b) Long-range communication by SSB (single side band) radio.

c) Short-range (within 200 miles of the airport) communication of VHF or UHF radio.

d) Local aids to navigation such as NDB (non direction beacon) or Vortac(direction plus distance.)

e) For approach and landing, an instrument landing system (ILS) or MODILS (a solid state ILS), which is presently under development.

f) PAR (precision approach radar) should be provided at airfields where the number of flights is of sufficient magnitude to justify such an installation.

g) The existing network of meteorological stations would have to be extended to provide adequate reporting of weather

conditions throughout the region.

Costs

The cost per ton-mile of air-freighting bulk commodities out of the Arctic will vary with the aircraft used and the opportunity for backhaul. In the movement of ores out of the Arctic, the aircraft would by flying southbound fully loaded. Cargo on the northbound leg would include industrial equipment and supplies as well as commodities needed for the support of personnel, but a small part of the aircraft's capacity. As a result overall load factors would not be expected to exceed 60%.

Direct operating costs (DOC) of an aircraft include crew costs, insurance, maintenance, oil, fuel and depreciation. Assuming that indirect costs are 60% of DOC and that the overall load factor is 60%, the following represents estimates of costs by aircraft types.

Aircraft Freighter	Direct operating Costs* Per ton mile (Can ¢)	Total Costs Per ton mile (Can ¢)
DC-6A	10.8	28.8
CL-44	5.4	14.4
Lockheed Hercules	5.2	13.9
Boeing 707	4.7	12.5
Douglas DC-8	3.8	10.1
Boeing 747	3.3	8.8
Lockheed L-500	2.7	7.2

. / .

* Includes crew, insurance, maintenance, oil, fuel and depreciation. For aircraft in operation costs are based on operators' experience. Direct operating costs of aircraft under development are derived from manufacturers' literature.

Cost ./.

The aircraft industry has succeeded in reducing costs per ton-mile through the introduction of larger and faster aircraft, and the yet-to-be produced Lockheed L-500 will continue this trend. However, it is still relatively expensive to move bulk commodities by air and it can be economically justified only in the case of commodities with a high value to weight ratio.

RAILWAY

General:

Rail lines have been constructed over permafrost and are operating successfully today.(1) By utilizing the experience of these lines, the pitfalls of building a railroad over Arctic permafrost could be avoided. There would, of course, be the expected additional construction costs resulting from remoteness and climate.

A major economic consideration in the construction of a line to move a non renewable resource is that the investment in the railway must be amortized over the economic life of the resource..

Unit Train:

The movement of a large volume of a particular ore or concentrate between one origin and one destination is best handled by a unit train(2). The size of each unit train and the number of unit trains would be dictated by annual tonnages to be transported, grades and curves on the line, and the

./.

(1) The Hudson Bay Railroad from The Pas to Churchill, Manitoba; The Quebec North Shore & Labrador Railway from Sept Iles to Schefferville, P.Q.; The Great Slave Lake Railway from Peace River, Alberta to Hay River and Pine Point in the Northwest Territories.

(2) Trains which handle a single bulk commodity on any given run in an assigned service between specific origins and destinations.

distance to be travelled. Although unit trains carrying up to 300 jumbo sized cars and travelling at speeds close to 100 miles per hour are being predicted for the future, it is rather doubtful that trains of this size could be justified in the Arctic. Based on present operating practices, a unit train in the north might be comprised of from 40 to 160 cars with a capacity of 100 tons each. If wind loss could be tolerated, open gondola cars would be used; otherwise, covered cars with hopper bottoms would have to be considered. It is estimated that average speed of the train would be 25 mph. Quick loading and unloading terminals would reduce terminal time to a minimum. The number of trains running on a given line would be limited by signalling (centralized traffic control), passing tracks, maintenance facilities and terminal facilities. The unit train would travel on a single track line which would probably be exclusively used for the transport of the resource commodity.

Unit Train Costs

The laying of a rail line in the Arctic is an expensive proposition. Estimates of construction costs vary from \$250,000 to \$500,000 per mile. Assuming an average cost of \$350,000 per mile, a 500 mile line would cost \$175 million to construct. Terminal facilities would add another \$½ million to \$2 million.

The rail cars would be made of standard steels and steels with a high tensile strength capable of resisting impacts at low temperatures. Gondola type cars would cost about $20,000 each. One diesel engine, costing about $300,000 would be required for each 25 cars. The ratio may vary depending upon the steepness of grades.

In estimating costs, it is assumed that:

a) The Unit Train would carry but one commodity;

b) The operations, including loading and unloading would be automatic; and

c) Crews would be required for emergencies only.

Operating costs are a function of tonnages to be handled, length of train, size of cars, grades and curvatures. Estimated operating costs of a unit train are:

Operating and maintenance of cars	2.7¢ per car mile
Fixed maintenance	$2500/mile/year
Back shopping charge	$500/mile/year
Fuel Cost per 2500 BHP diesel	1¢/BHP/hr.

Ton mile costs for unit trains are developed in Appendix X.

AIR CUSHION VEHICLES

General:

Air Cushion Vehicles (ACV's) have been tested and used in an Arctic environment, and their feasible use may include the following:

- i Off-road transport of goods and personnel.
- ii Lightering of freight.
- iii Surveying and prospecting.
- iv Search and rescue.

Basic Vehicle Types:

i - The fully amphibious ACV is supported on a cushion of pressurized air. A flexible skirt contains the air underneath the hull. The fully amphibious ACV is characterized by powerful engines and high performance. It can have a service speed in excess of 60 knots and be capable of speeds of 70 knots or more. It can overcome obstacles up to 3/4 of its skirt height and travel on hilly terrain. Air screws mounted atop the vehicle provide forward propulsion.

ii - The marine only ACV uses rigid sidewalls and flexible front and rear skirts to contain pressurized air underneath the hull. Propulsion is by conventional marine screw, or by a combination of a marine and an air screw for high speeds.

Basic vehicle types ./.

iii - The off-road ACV would be partially supported by a cushion of air and would run on wheels for traction and control. In areas of rugged terrain, some route preparation would be necessary. It would be particularly suited to travel over ground that is incapable of carrying heavy wheel loads. The off-road ACV concept is in the stage of research and development.

iv - The tracked over-land vehicle (or train of vehicles) is still experimental. It would utilize a prepared track as does a railway or monorail system. Propulsion would be by conventional air screw or by a recently developed linear induction motor. A tracked overland vehicle would be capable of high speeds and would have the ability to climb steep gradients.

Arctic Operation :

The fully amphibious ACV in comparison with other ACV's has the widest range of potential uses in the Arctic and has already been subject to trials*. An SRN5 proved itself capable of handling

./.

* "Trials of an SRN5 Hovercraft in Northern Canada Spring 1966" Defence Research Board, Oct. 1966.

a variety of surface and climatic conditions. The only conditions which provided problems were those of severe ice break-up on the Mackenzie River and rough sea ice.

The marine only ACV is limited in operation to open water and between points with docking facilities. This greatly limits the time of year and the routes that a marine only ACV can operate. One conceivable use would be on the Mackenzie River during the summer. However, costs per ton-mile would be 10 to 20 times as high as those of river barges.

High capital and operating costs limit the uses of the ACV*:

Type of ACV	Capital Cost (Can $)	Payload tons	Service Speed (knots)
HM2 marine only	200,000	5	30
HM4 marine only	1,800,000	60	35-40
SR-N6 amphibious	350,000	3	56
SR-N4 amphibious	4,500,000	60	61

*"Comparison with Competitors", R.E.A. Lyne, British Shipbuilding Today. Operating costs were altered to reflect anticipated costs in the Canadian Arctic.

Estimated Operating Costs in Can. $

	HM-2	HM-4	SR-N6	SR-N4
Insurance/year (3% capital costs)	$6,000	54,000	10,500	135,000
Crew/year	$55,000	110,000	55,000	110,000
Fuel and oil/hour	$14.00	154.00	32.50	325.00
Maintenance/hour	$11.00	140.00	52.00	394.00
Overhead/hour	$20.00	125.00	70.00	290.00

Ton-mile costs are developed in Appendix XI

The ability of the amphibious ACV to operate on both land and water may result in the ACV being economically viable in some operations. Specifically, lightering operations as presently undertaken, cost from $15 to $45 per ton. These costs exclude the additional handling of commodities from the beach to a marshalling yard or warehouse. The fully amphibious ACV appears particularly suitable for lightering as it would offer the following advantages:

a) Faster unloading.

b) Direct movement from ship to marshalling yard or warehouse.

c) Extension of season.

d) Elimination of dock capital cost (if one is necessary, utilizing the present lightering systems).

An ACV suitable for lightering has yet to be designed, but is technically feasible. In the development of such a vehicle, a

prime requirement would be ease of maintenance and repair without sophisticated equipment, facilities and technicians.

The off-road transport of goods over terrain unsuited to wheeled vehicles and between points without airfields could also be handled by ACV's. The ACV's ability to traverse untracked terrain and travel on water may result in its being used in surveying and prospecting, as well as search and rescue work.

Future Developments

a) Advanced studies, being conducted in the United States of future ACV's indicate that for sidewall craft, an all-up weight of 4000 tons is the most suitable for trans-oceanic travel.

b) Development of improved skirts, in order to reduce the power requirements of the amphibious ACV is presently being researched. This would enable smaller amphibious ACV's (under 100 tons) to use diesel power, thereby reducing capital, maintenance and running costs. Of significance, also, would be the employment of mechanics trained to maintain and repair diesel as opposed to gas turbine motors.

c) An interesting concept is the use of the amphibious hovertrain for travel over selected routes such as the Mackenzie River. The "engine" of the train would consist of one or more amphibious ACV's with vertical lift and horizontal propulsion. The number of ACV's providing propulsion would depend on the operating speed desired.

The "engine" would pull a number of freight carrying ACV's, each equipped with vertical lift only.

A train such as this could travel the Mackenzie River, winter and summer, at speeds of 30 miles per hour and more.

d) A significant development, which may play an important role in the future of ACV's in Canada's Arctic is the banning by the Government of Alaska during the summer of all heavy wheeled and tracked vehicles for off-highway use over permafrost terrain. The reason for this is that wheeled and tracked vehicles make depressions in the permafrost which disturb the insulation properties of the surface, thus causing the

permafrost to thaw and erode along the depression. Only helicopters and ACV's will be allowed to carry supplies over routes previously serviced by heavy wheeled and tracked vehicles.

MONORAIL

General:

The monorail is a high capacity mode of transport, requiring the movement of large volumes of a product for economic operation. Monorail cars to carry bulk materials, as well as the related loading and unloading systems, have yet to be designed. The knowledge and techniques which presently exist for the construction of foundations on permafrost, however, are adequate for the design of the support structures of a monorail system in Canada's Arctic.

Proposed Operational Characteristics.

In order to move heavy bulk materials the ore cars would be of 20 ton capacity each, 40 feet long and capable of speeds averaging 60 mph. Each 20 ton car would use 300 kwh of electricity. An interesting proposal advanced recently by North American Express Monorail Corporation is that by using the support structures of a monorail system, a 24 inch pipeline installed within the monorail beam could be incorporated without difficulty. The wellhead temperature of the oil could be maintaned by insulation or by electrically heating the beam.

Costs of Monorail

Prefabricated rail and supports, together with the necessary electrical components, would cost in the vicinity of one million dollars per mile. Construction and related costs would increase the capital cost of the line, excluding rolling stock, to three million dollars per mile.

The cost of the proposed cars is approximately one hundred thousand dollars per car while maintenance per car is anticipated to be not greater than $4600 per year with an utilization rate of 1000 hours. Ton-mile costs are developed in Appendix XII

The high costs associated with the monorail make it an uneconomic mode of transport to move bulk materials in the Arctic regions at present. As the Arctic develops and the need becomes more apparent in some areas to move large volumes of materials, as well as supplies and people, quickly, then the monorail may become economically feasible.

OFF - HIGHWAY VEHICLES

Although a number of special purpose vehicles capable of traversing marsh, swamp, muskeg or permafrost terrain are being tested and developed, certain characteristics make them uneconomical for the transportation of bulk materials within the Arctic region. In some cases, the requirement of high mobility necessitates reduced payload capacity and results in a large initial capital cost. Slow speeds and high operating costs are other factors making these vehicles economically unattractive. Until these vehicles are further refined and developed, conventional surface vehicles, trucks and tracked carriers, must be used over roads appropriate to the climatic conditions in the Arctic.

Ice roads are being used extensively to accommodate conventional surface vehicles in many areas of the Arctic and have proven much less costly than conventional roads. They are easy to construct and generally are usable from December through April. They are constructed by plowing to expose a hard packed ice surface. Overland a bulldozer is used to cut the initial track because of the rough and rocky terrain. On lakes and rivers trucks are used because of their speed and generally flat and uniform surface conditions. The first trucks or tracked vehicles to use the ice road over the rivers and lakes at the beginning of the season encounter cracking of the ice, and half loads are standard. Water seeping through these cracks continually

builds up the thickness and strength of the surface layer.

Transportation by truck and cat train allows movement of supplies from origin to destination without time consuming and costly intermediate loading and unloading operations. However, movement of goods is hindered by late freeze-up or early break-up of lakes, rivers and muskeg.

Adverse weather conditions, mechanical failures, communications problems, and loss of vehicles through the ice are problems which must be faced continually in the Arctic.

Types of Highway Vehicles in Use:

Cat Trains:

A typical cat train consists of five freight sleighs with an accommodation caboose. It is pulled by a crawler-type tractor, and equipped with a radio and maintenance equipment. Cat trains usually travel in pairs for safety.

Trucks :

In order to attain maximum efficiency from trucks, the ice road must be well prepared. As with cat trains, trucks usually travel in groups, especially when a plow truck is not present. The most serious and frequent problem encountered is ice ridges. Average gross

vehicle weight of trucks travelling over ice roads in the north is 90,000 pounds with a payload of 50,000 pounds and an average speed of about 25 mph. If the grades are not too severe, an extra trailer is added to the truck. Trucks are outfitted with a caboose in which the driver eats and sleeps. A twenty-hour work day is quite normal for such operations.

Ton-mile costs of a tractor-trailer operation are developed in Appendix XIII.

CONVEYOR BELT

General:

Overland belt conveyors are of three basic types:

i. Conventional rubber belt conveyor with fabric core.

ii. Steel cord rubber belt conveyor.

iii. Cable belt conveyor.

The conventional and steel cord conveyor belts carry the load from head to tail of each unit or flight with the entire length of the belt in tension* and running on rotating idlers.

The cable belt conveyor carries the tension in two cables running on sheaves over the length of the conveyor. The belt lies on the two cables which are close to the edge of the belt. The belt is formed by moulding lateral steel straps in a fabric which, in turn, is covered with rubber. The load on the belt is then transferred to the two cables by way of the lateral steel straps.

Conventional belt conveyors have lower allowable tensions than the other two types and therefore long runs necessitate having several flights. Each flight requires head and tail terminals, drives, controls, transfer chutes and transfer house structures.

---

* The fabric core and the steel cord carry the tension.

General:

Single runs of up to $5\frac{1}{2}$ miles have been designed, using the steel cord and cable belt conveyors. However, using conventional fabric core belting, a $5\frac{1}{2}$ mile run would require approximately six separate flights, provided the total vertical lift is not excessive.

Cost of Belt Conveyors:

The Putnam Coal Mine in West Virgina carried out a cost study of the three types of belt conveyors described to determine which would be the most economical to carry crushed coal over a length of 27,500 feet and vertical lift of 130 feet. Capital and operating cost estimates for this project were as follows:

Conveyor Belt Type	Capital Cost (U.S. $)	Operating Cost (U.S. $/year)
Conventional Belt Conveyor	3,400,000	260,000
Steel Cord Belt Conveyor	3,900,000	155,000
Cable Belt Conveyor	3,000,000	230,000

Assuming a cost of capital of 8% and a 15 year amortization period, the total annual costs (capital plus operating) of these belt conveyors are:

Cost of Belt Conveyors ./.

Conveyor Belt Type	Annual Costs (U.S.$)	Cost/ton (U.S.¢)	Cost/ton-mile (U.S. ¢)
Conventional belt conveyor	658,000	18.8	3.6
Steel cord belt conveyor	611,000	17.5	3.4
Cable belt conveyor	581,000	16.6	3.2

The unit costs are based on transportation of 3,500,000 tons of crushed coal per year. The belt conveyors were designed to carry 50 pounds per cubic foot at a capacity of 1200 tons per hour on belt widths of 42 inches for conventional and cable belts and 36 inches for steel cord belt. These figures do not account for the added costs associated with construction and operation in the Arctic. These are provided in Appendix XIV .

The unit costs per ton-mile associated with conveyor belts can be decreased if the capacity of the belt is increased. This could be achieved by:

a) Increasing the belt speed.

b) Increasing the belt width, or

c) Increasing the unit weight of the material carried.

TRANSPORTATION COSTS OUT OF THE ARCTIC*

The available and anticipated Arctic transportation modes can be generally classified, for the purpose of moving bulk commodities, as "transportation in the Arctic" and "transportation out of the Arctic". The former refers to the movement of the bulk commodity from the mine or well head to an ocean port, a railhead, or a major oil pipeline. The modes capable of doing such tasks include airplanes, conveyor belts, monorails, air cushion vehicles, off-highway vehicles and feeder pipelines. Costs per ton-mile vary greatly among these modes but in every case these costs exceed those incurred by modes specializing in "transportation out of the arctic".

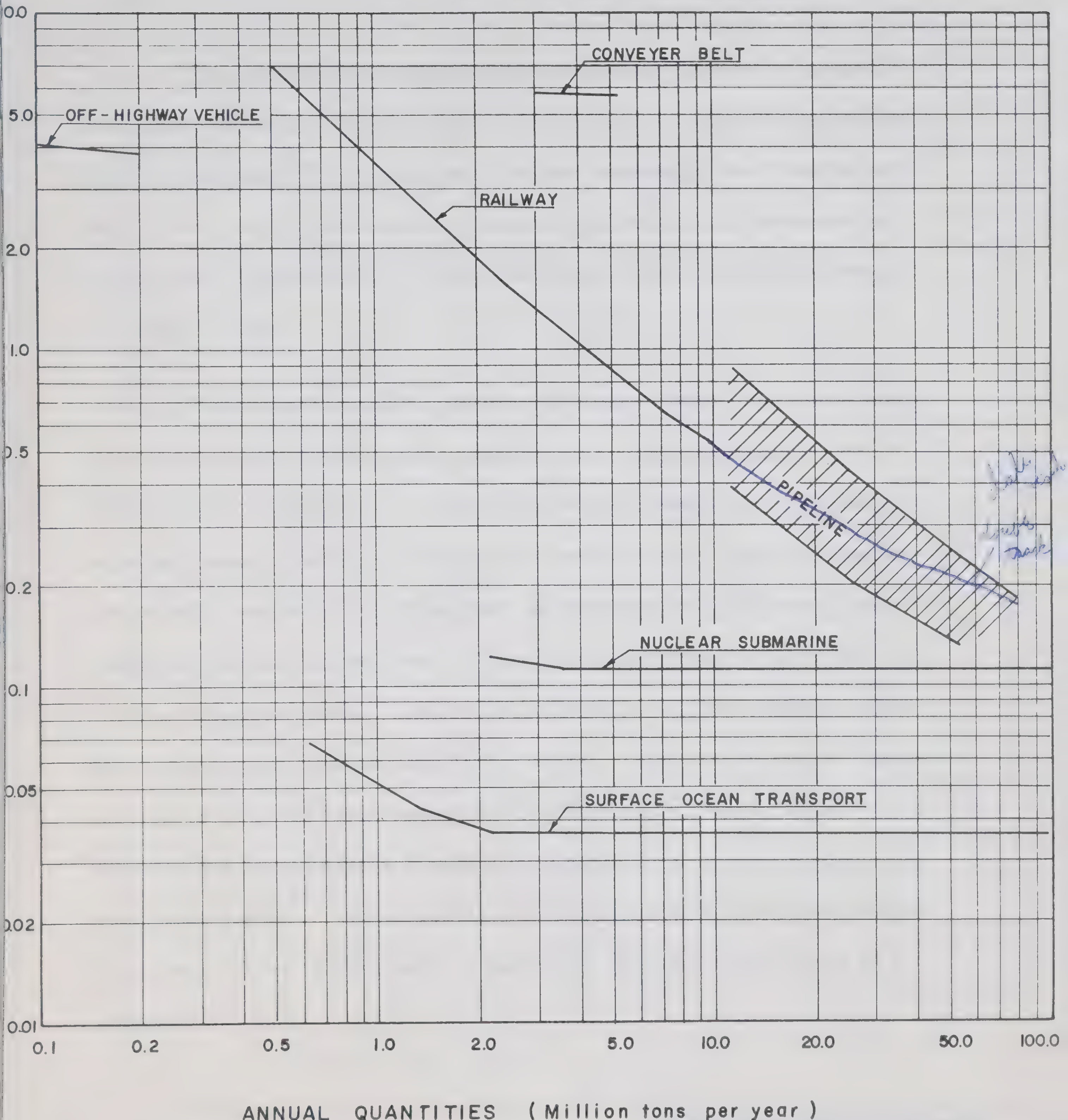
The "transportation out of the arctic" modes - submarine supertankers, dual purpose bulk carriers, big inch pipelines and unit trains require massive capital expenditures, but feature very low operating costs. As a result, average costs per ton-mile tend to decline as the quantity of bulk commodities moved increases. Referring to Figure 4, this is quite apparent for railway, pipelines and surface ocean transport and less so for nuclear submarines. For both bulk carriers and submarines ton-mile costs flatten out when annual quantities are such that the largest size craft (250,000DWT in both cases) can be used. It is assumed that vessels built for Arctic navigation would be used at rated

./.

* ALL COSTS DEPICTED IN FIGURES 4 AND 5 ARE EXCLUSIVE OF PROFIT INSURANCE AND CONTINGENCIES.

FIGURE 4

COSTS OF TRANSPORTATION AS A FUNCTION OF ANNUAL QUANTITIES



capacity 12 months per year, either in the Arctic or elsewhere.

The capital cost estimates for submarines indicate very small economies of scale. By increasing cargo capacity by 2/3 (from 150,000 DWT to 250,000 DWT), the capital cost per deadweight ton drops by only 4%. In the case of bulk carriers, when cargo capacity is increased by 130% (from 65,000 DWT to 150,000 DWT) the capital cost per deadweight ton drops by 32%.

Before bulk carriers, submarine supertankers, pipelines, and unit trains can be economically justified, very large movements of bulk commodities are required. Unit train costs are less than 1 cent per ton-mile for annual quantities in excess of 4 million tons. Big inch pipelines are rarely considered for throughputs of less than 500,000 barrels per day (about 26 million tons per year). This represents costs in the order of .2¢ to .4¢ per ton-mile. The range of costs for big inch pipeline reflect the range of construction costs in the Arctic. The bottom line of Figure 4 is based on a 42 inch line costing $375,000 per mile, while the top line is based on the Trans Alaska Pipeline estimate of $1 million per million for a 48 inch pipeline. The proportion of permafrost along the route and the ruggedness of the terrain will, in part, determine the actual costs of a pipeline.

Transportation costs out of the Arctic ./.

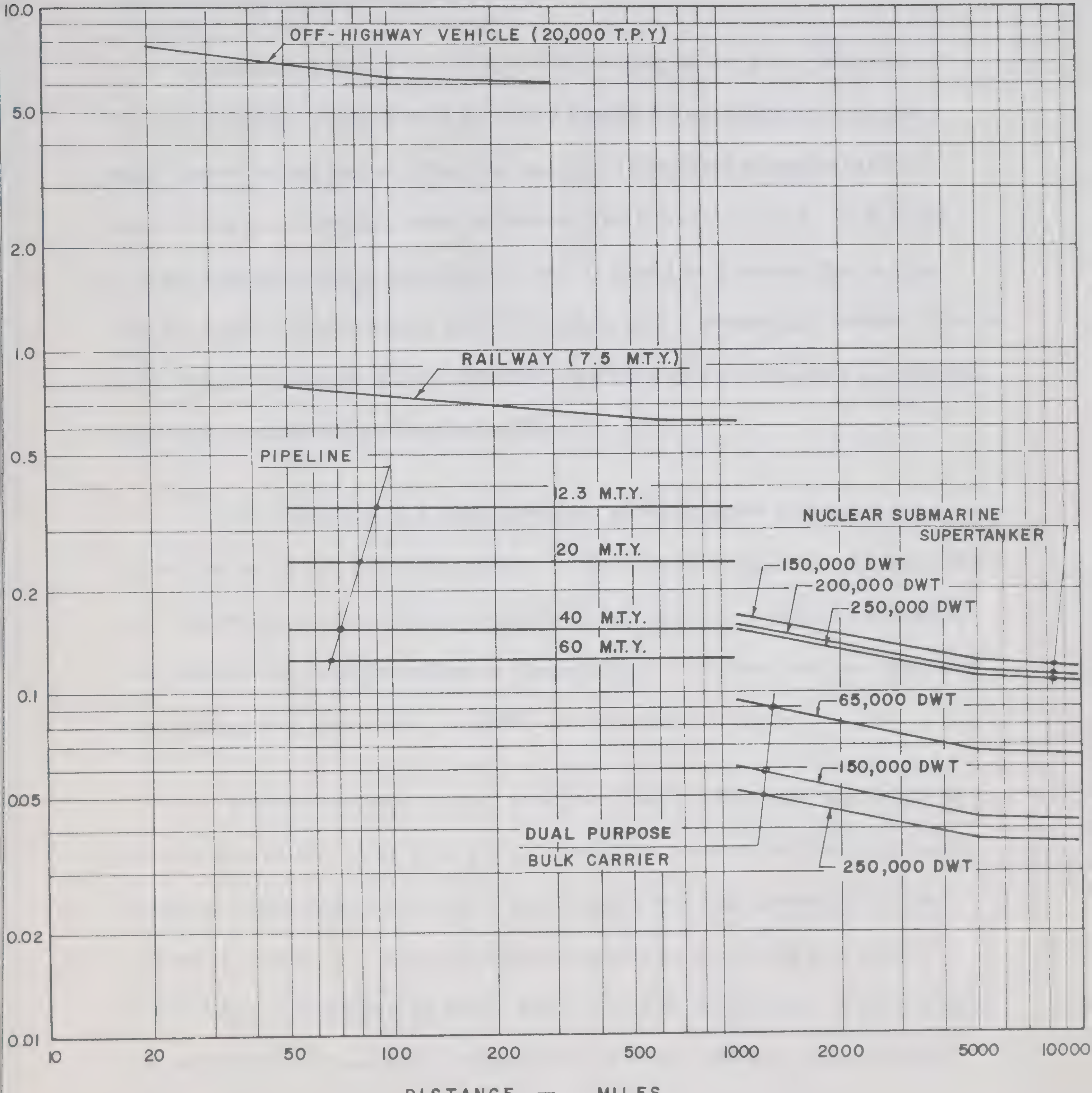
The cost curve for surface ocean transport flattens out at $2\frac{1}{2}$ million tons per annum; at this point costs are .037¢ per ton-mile. Nuclear submarine costs are .112¢ per ton-mile for annual quantities in excess of $3\frac{1}{2}$ million tons.

Figure 5 depicts the variation in transportation costs with delivery distance. For each mode, an appropriate volume assumption is made, based on existing or hypothetical resources. In the case of the railway (unit train), it is assumed that 7.5 million tons are moved annually - corresponding with the estimated potential production of iron ore concentrate at Snake River. If the concentrate is to be transported 50 miles, costs will amount to .792¢ per ton-mile. A line of 1000 miles reduces costs to .629¢ per ton-mile. The reduction in costs is a result of a smaller proportion of terminal time being spent in on-loading and off-loading the concentrate on a 1000 mile run.

Figure 5 contains four curves representing four different throughputs for an oil pipeline. In each case the pipeline is assumed to be a 42 inch diameter line costing $375,000 per mile. For a given throughput there is virtually no change in costs as delivery distance varies. Operating costs and capital costs vary directly with mileage; this results in negligible changes in ton-mile costs over distance.

FIGURE 5

COSTS OF TRANSPORTATION AS A FUNCTION OF DISTANCE



Transportation costs out of the Arctic ./.

If Humble Oil, as a result of the sailing of the S.S. "Manhattan", decides that dual purpose bulk carriers cannot be operated on a twelve month basis in the Arctic, then the nuclear submarine supertanker may come in for considerably more attention than it has received. If it could be built and operated at forecasted cost, it would be cheaper than a pipeline for annual volumes less than 75 million tons (assuming pipeline costs of $375,000 per mile) or annual volumes less than 150 million tons (assuming pipelines costs of $1 million per mile).

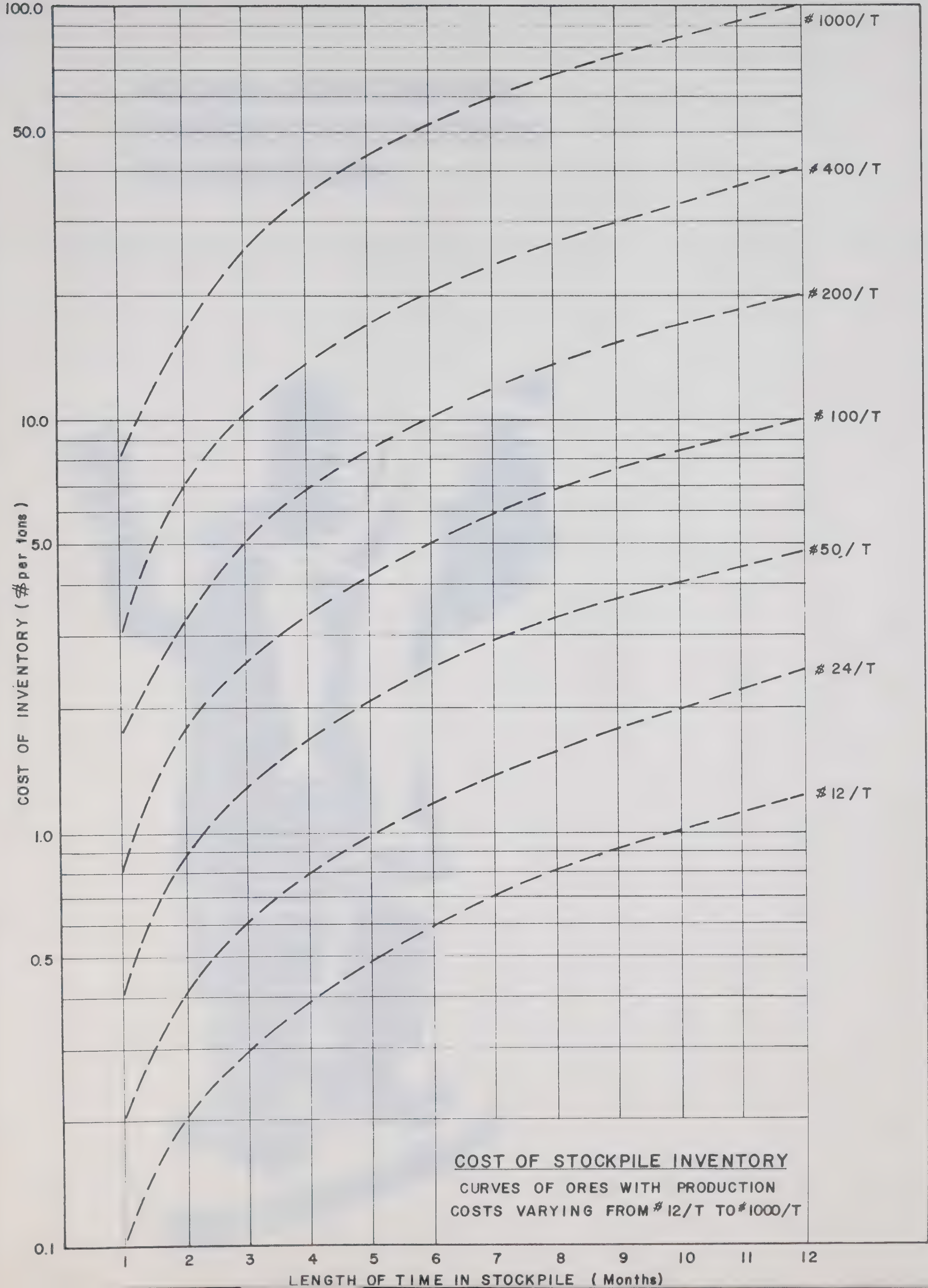
The selection of a transportation mode to move a resource out of the Arctic is not solely dependent on the cost of transport. Some modes are operable for only a limited period of the year e.g. barges on Hudson Bay and the ice road from Rae to Coppermine. One then has the choice of stockpiling until the mode is usable or utilizing air cargo.

Figure 6 relates cost of inventory stock piling with the length of time in stockpile. Ores with a high production cost would obviously have relatively high inventory costs. Referring to the map presented in the summary (Page 11), the cost (including profit) of moving ore from Tehek Lake to Winnipeg by barge and rail is $18.85 per ton. Unfortunately the period of the year when barges can use Hudson Bay is very limited.

Transportation costs out of the Arctic ./.

An alternate mode of transport is air cargo at a cost of $73.50 per ton, exclusive of profit and insurance. To simplify the example, assume that air cargo costs, including profit and insurance, amount to $78.85 per ton; this indicates a cost differential of $60 per ton for the two modes. If the production costs of the metal amount to $1000 per ton, storage costs would attain $60 per ton for seven months (figure 6). This would indicate that, given the assumptions listed above, the mine operator should use air cargo for a limited period to minimize transportation and storage costs. If Hudson Bay can be safely navigated for 3 months of the year,at the termination of navigation the metal should be flown out for approximately two months.

FIGURE 6



COST OF STOCKPILE INVENTORY
CURVES OF ORES WITH PRODUCTION COSTS VARYING FROM $ 12/T TO $ 1000/T

Analysis of land terminal installations and harbours at selected sites

ANALYSIS OF LAND TERMINAL INSTALLATION AND HARBOURS AT SELECTED SITES

General:

Design criteria of mooring facilities for extended or year 'round operation in the Arctic has not, as yet, been established. As an example of the wide variation in design criteria for this region, the following was established by different companies for the design of platforms in Cook Inlet, Alaska.

a) Multi-Well drilling platform

Ice, 6 feet thick bearing on one half of all members exposed and three feet thick bearing on the other half at an ice pressure of 43,200 pounds per foot. In addition an iceberg 20 feet x 50 feet x 50 feet (approximately 1500 tons) striking at 9 feet per second, with the platform absorbing 50% of impact combined with ice two feet thick on all legs.

b) Multi-Well drilling platform.

A lateral force of 120,000 pounds per foot of leg diameter on two legs and 50,000 pounds per foot of leg diameter on the remaining legs, in addition, a 1500 ton mass striking one leg at 10 feet per second.

c) Oil loading terminal

P = 150 D on any bent.

where P = force in thousands of pounds.

D = leg diameter in feet.

The Arctic design criteria for a terminal in the open seas would be somewaht different as it would include forces from moving ice with less velocity but with a much larger mass. To try and arrest this energy with a normal dock structure would be so costly as to be impractical. Alternate solutions must therefore be investigated.

The use of extremely strong fixed structures with sloping sides to intercept the moving ice field is a possible solution. The approaching ice field would slide up the sloping side and, as it spans between the structure and the water surface, the ice would break up. These structures must be separated from the mooring dock to prevent ice build-up on the dock structure.

In any steel structure forming part of an Arctic terminal, dock, or mooring structure, the use of high tensile steels, and steels with high resistance to shock loads at extremely low temperatures must be investigated along with the standard grades of structural steel.

General ./.

Pneumatic bubbler systems* should be an integral part of any Arctic terminal and would operate all winter to keep the dock area ice-free, or at least reduce the ice thickness, facilitating navigation and restricting ice damage to dock structures.

Ice Islands:

As a means of intercepting moving ice flows, the University of Alaska has been conducting experiments with grounded icebergs about 20 miles from the north slope of Alaska in 85 feet of water with about 40 feet of the iceberg above water level. Commencing early in 1969, the surface of two of the icebergs was built up by spraying them with sea water, resulting in ice build-up as high as 12 inches per day. The object was to increase the weight of these ice islands and hence increase their resistance to sliding on the sea bed.

Ice making ceased in April as the weather was not cold enough for efficient ice production. To insulate these ice islands against warm weather, material was pumped from the sea bed to cover the surface of the ice island. ./.

* A system composed of a compressor at ground level connected to runs of pipe on the sea bed. The submerged pipe contains small holes to permit the escape of air which rises to the surface as small bubbles.

General ./.

The long-range objective of this experiment is to investigate ice flow patterns as they come in contact with the islands and also to investigate the effect of bridging between the islands which are located about 300 feet apart. The use of a string of ice islands to act as an ice-break to protect a mooring facility has great possibilities with obvious economies compared to man-made rock islands.

If the ice island is not practical* rock islands could be built to arrest and deflect the ice flow; however, this would be extremely costly.

A compromise that should be investigated would be very low rock islands (to reduce the rock volume required) built up to a greater height with ice during cold weather.

Bubbler System:

In order to relieve a dock structure from damaging forces caused by ships moving through heavy ice in the vicinity of the dock, it is desirable to deter ice accumulation and reduce ice thickness as much as possible.

---

* The ice islands bult by the University of Alaska melted at the end of the summer, 1969,

General ./.

It is known that ice formation can be retarded or ice cover melted by:

a) Mixing lower water layers with upper layers to increase salinity of surface layers in order to inhibit the growth of ice crystals.

b) Creation of vigorous, erosive flow of a large mass of water in the area where ice control is desired.

c) Addition of heat to the mass of water in motion in the area to be kept cleared of heavy ice.

To date, air bubbler systems and circulating propellors have been employed, both separately and together, to achieve some degree of ice control. A device, in the form of a compact high pressure, forced draft, crude oil-fired furnace to produce the combined beneficial effects of the above two systems could be developed to generate a vigorous flow of a large mass of heated water, both in the dock and mooring areas.

Bubbler System ./.

The products of combustion from this device would provide a stream of hot gases discharged at a suitable depth, thereby inducing a vigourous and direct flow of heated water admixed with gas bubbles.

A series of such devices or gas jet producers, utilizing an economical fuel and mounted either on the dock, on separate structures, or ashore, may be adequate to retard ice formation or, at least, reduce ice thickness to within tolerable limits at the dock and along the approach and exit channels to the dock.

Berthing Facilities

Dock structures suitable for erection in short construction seasons must be used. A prefabricated steel barge with holes in the deck through which large steel caissons are threaded and driven, or socketed, into the ocean floor is one possible type. The barges and caisson tubes would be fabricated in a shipyard, then towed along with the necessary construction equipment to the site during one season, with erection either to start immediately or the following season, depending upon conditions.

For any proposed dock facility, other types of structures must also be considered such as concrete cribs, timber cribs, sheet steel piling cells, steel caissons, steel piling and tied-back sheet piling.

Berthing Facilities ./.

Various dock configurations must also be analyzed for each particular operation such as finger pier, L-pier, T-pier, marginal lock and slip.

An alternative to a fixed berthing jock would be a single buoy mooring (SBM). Many believe that SBM's are not possible in the Arctic because:

a) moving ice forces tend to tear the buoy loose

b) ice builds up on the deck of the buoy; and

c) difficulties are encountered in berthing and connection.

The advantages of a SBM are so great, however, that enormous savings in terminal facilities are possible if these disadvantages can be overcome.

To eliminate or reduce moving ice forces on an SBM, a break of islands (ice islands, rock-fill islands, or combinations) could be constructed.

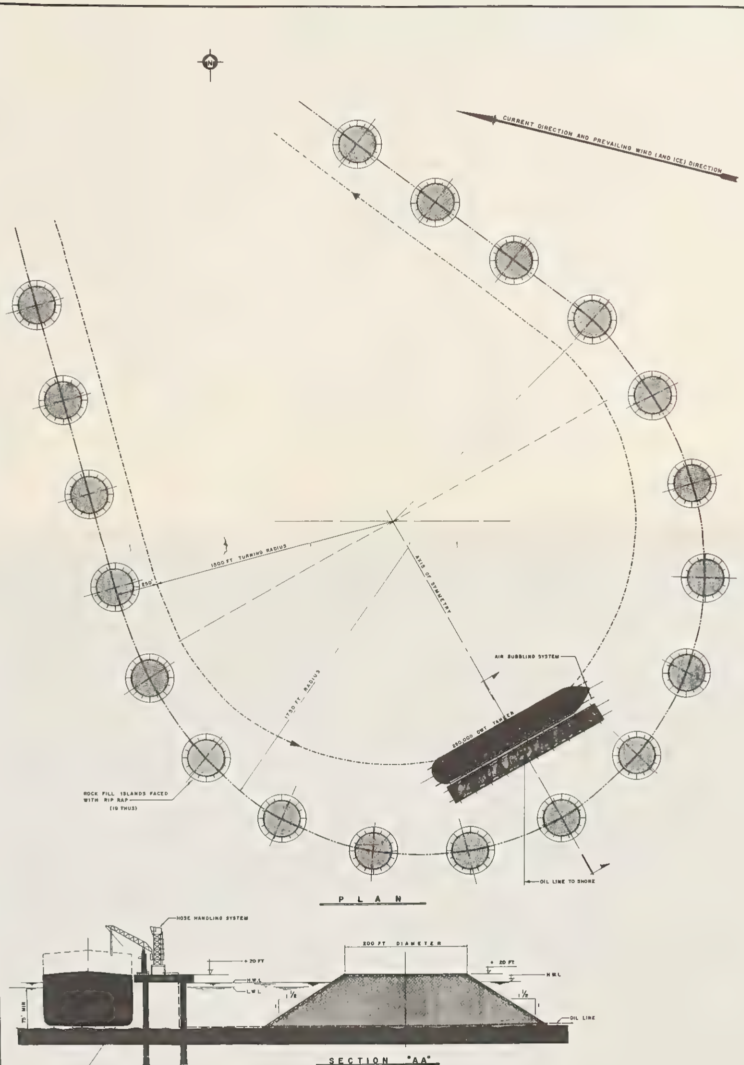
Surface ice build-up on the buoy deck could be eliminated, or reduced, by the introduction of heat into the buoy. By using heat in the oil at well head (at least 150°F.) or by burning crude, enough heat can be introduced into the buoy to stop ice growth.

Berthing Facilities ./.

Ships are moored to a SBM by head ropes only and are free to lie in whatever direction is dictated by wind and current conditions as the crude oil is pumped aboard the tanker. No tug assistance is required for either berthing or unberthing. A line boat is, however, required for berthing and connecting up. Such an operation in icy waters would require a heavily ice-strengthened line boat. An ice-breaker, operating on a full time basis, may have to be considered.

Mackenzie Bay Terminal

A marine terminal can be located in this area within a few miles of shore, at either Herschel Island (Site "A") or on Mackenzie Bay (Site "B") about 30 miles south-east of Herschel Island. At either location, 90 feet of water exists at a reasonable distance from the coast. Proceeding eastward along the coast from Site "B", the 90 foot water depth line runs at least 30 miles offshore until Cape Bathurst, some 300 miles to the east. At either Site "A" or "B", a typical harbour arrangment might be as illustrated in Drawing (A). The number of rock islands would be determined through intensive investigations.



TYPICAL DOCK CONSTRUCTION

McKENZIE DELTA AREA

DRAWING "A"

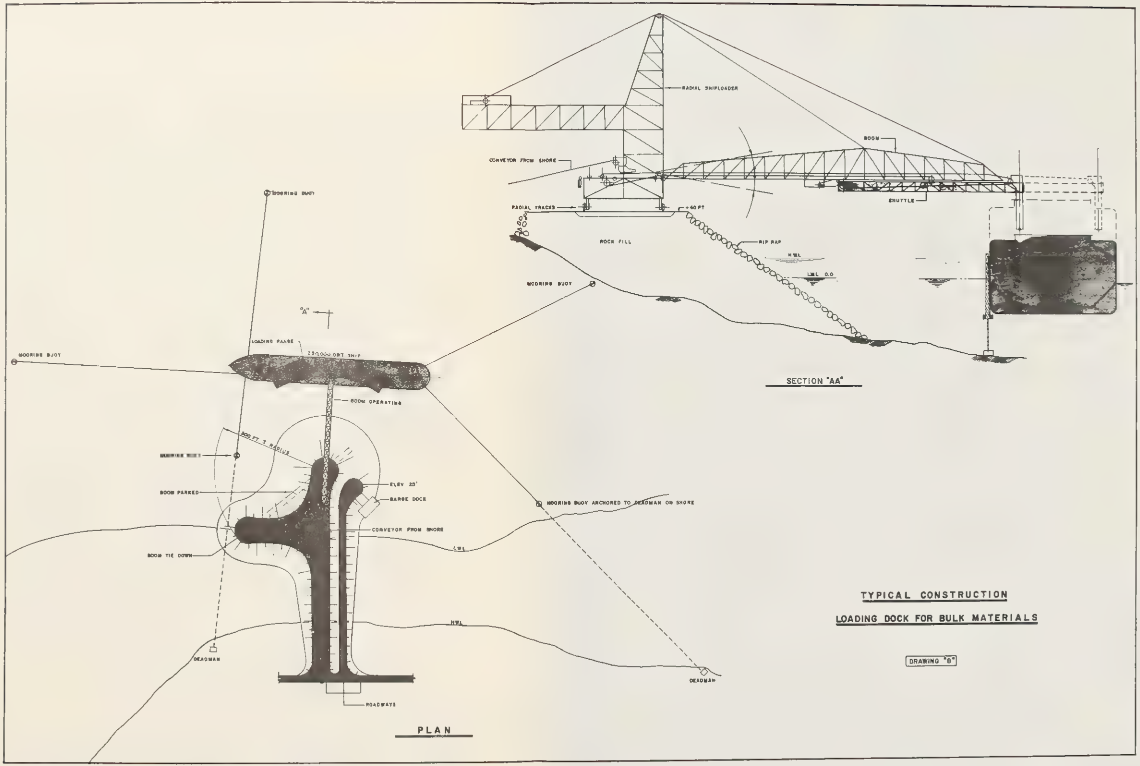
Melville Island Terminal:

A structural steel mooring facility similar to that proposed for Mackenzie Bay should be investigated for this location. As deep water exists close to shore and as rock is available, rock backing to the steel structure will help resist ice and ship berthing forces. A single buoy mooring could also be considered for use at this site.

Coppermine and Little Cornwallis Island Terminals:

At both these harbour sites, the product (copper at Coppermine, lead and zinc at Little Cornwallis Island) could be most expeditiously loaded aboard the ship by a belt conveyor system. The low annual tonnage cannot support the high dock cost that would be necessary to withstand the winter ice forces. A typical installation using a multiple buoy mooring system is shown on Drawing (B); permanent docking facilities are not required.

A rock-fill causeway would project into the sea, a distance dictated by the combination of ship size, economic length of the shiploader boom, bottom contours, and cost of rock-fill. If a rock bluff existed with deep water very close to shore, as is the case at Expediter Cove near Coppermine, then benching the rock bluff to receive the foundation of the shiploader would provide a solution that may be less costly than the rock-fill illustrated in Drawing (B).



TYPICAL CONSTRUCTION

LOADING DOCK FOR BULK MATERIALS

DRAWING "B"

Coppermine and Little Cornwallis Island Terminals ./.

The timber spar buoys and their anchors would be placed at the opening of each season and taken in at the close of the season. These provide the ship captain with an approximate berthing position. The steel mooring buoys would be placed at the same time as the timber spar buoys and would also be taken in at the close of the season. A light cable is connected to the buoy riser chain and is run ashore and anchored where it can easily be located for re-setting the buoys at the start of navigation the following summer.

With this procedure, the heavy anchors and chains can be left in place from year to year. Shiploader belt capacity would be in the order of 1000 tons per hour at Coppermine and 2500 tons per hour at Little Cornwallis Island. With berthing, unberthing, shifting shiploader from hatch to hatch, trimming, and minor delays, the shiploading rate should average about 50% of belt capacity, enabling a 10,000 DWT ship to be loaded in about twenty hours at Coppermine and a 50,000 DWT ship to be loaded in about 40 hours at Little Cornwallis Island.

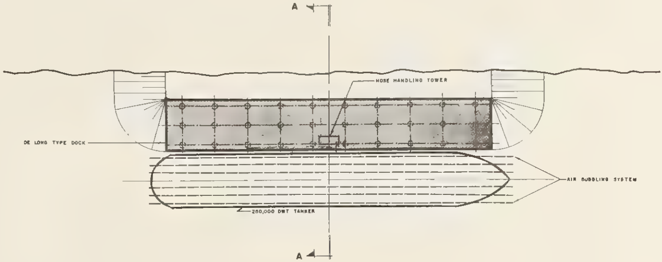
Axel Heiberg Island Terminal:

With the shipment of both oil and sulphur, a multi-use terminal must be investigated to examine whether one terminal can geographically satisfy both operations.

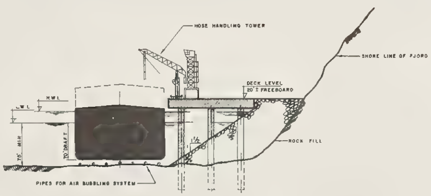
Conveyor belt loading of the sulphur would be carried out with shiploaders similar to the illustrated on Drawing (C) using either buoyed mooring or a fixed dock or a combination of a small breasting dock with buoys.

The terminal illustrated on Drawing (C) for shiploading sulphur assumes that the sulphur will be stored and shipped as dry, bulk sulphur. An alternate solution is to handle the sulphur in liquid form by pumping. To handle sulphur in the liquid state, a temperature of 270°F. must be maintained.

The liquid storage tanks on shore must, therefore, be insulated and heated to keep the sulphur at 270°F. In addition all pipelines must be insulated and traced. The tanker required to transpo liquid sulphur is of a special nature and the receiving ports for this ve must have special piping and storage facilities to handle liquid sulph



P L A N



SECTION "AA"

TYPICAL DOCK CONSTRUCTION
IN
FJORD

(APPLICABLE TO MELVILLE — AXEL HEIBERG AREA)

DRAWING "C"

Axel Heiberg Island Terminal ./.

Generally speaking , large annual volumes are necessary to justify handling of sulphur in the liquid state. However if the product from this site goes to one location, say Rotterdam, which already has facilities for receiving liquid sulphur, then liquid transport may be economically feasible. On the other hand, if this relatively small tonnage is shipped to several locations, dry bulk transport would probably be the cheaper solution. Once the projects and markets are known, both dry and liquid sulphur must be studied to optimize the total production and transportation costs.

If oil were to be shipped from the same terminal as the sulphur, the small breasting dock would contain oil loading arms.

As with other sites, the use of a single buoy mooring for oil must be investigated.

Baffin Island Terminal:

Considerable site investigation and preliminary design and estimation have been completed for the proposed Milne Inlet terminal of Baffinland Iron Mines Limited.

Baffin Island Terminal ./.

The proposed dock is a row of steel sheet pile cells, connected, rock-filled, and rock-backed between cells and shore. Dredging is necessary to give the required depth at ship entrance and dock face. Shiploading would be by twin-slewing shiploaders at 4000 tons per hour each.

With a rock bluff just north of the proposed dock area, and with deep water close to shore, it may be possible to effect capital cost savings by installing a multiple mooring berth as proposed at Coppermine and Little Cornwallis Island with twin shiploaders rated at 4000 tons per hour each, or more.

Cost of Mooring Terminals:

Lacking definite site locations, and without data on soil conditions and ice movement, any estimates must, of necessity, be little more than order of magnitude.

The following figures give some indication of construction costs for each of the terminals discussed.

a) Mackenzie Bay

Dock	$10,000,000
Mechanical and electrical	2,500,000
Bubbler System	2,000,000

Cost of Mooring Terminals ./.

	Engineering and contingencies	1,500,000
		$16,000,000
b)	Coppermine	
	Freight dock	$ 100,000
	Moorings	150,000
	Storage building	150,000
	Conveyors	350,000
	Shiploader	500,000
	Site preparation	250,000
	Electrical	200,000
	Mobile Equipment	100,000
	Engineering and contingencies	300,000
		$2,100,000
c)	Little Cornwallis Island	
	Freight Dock	100,000
	Moorings	150,000
	Storage building	1,000,000
	Conveyors	550,000
	Shiploader	700,000
	Site preparation	400,000

Cost of Mooring Terminals ./.

Electrical	$ 400,000
Mobile equipment	200,000
Engineering and contingencies	500,000
	$1,500,000

d) Baffin Island

Site grading	$2,000,000
Tracks	700,000
Docks	4,200,000
Mechanical equipment	5,500,000
Tank Farm	600,000
Electrical distribution	400,000
Freight	600,000
Engineering and contingencies	2,000,000
	$16,000,000

e) Melville Island

Dock	$4,500,000
Mechanical and electrical	2,000,000
Bubbler System	1,500,000
Engineering and contingencies	1,200,000
	$9,200,000

Cost of Mooring Terminals ./.

f) Axel Heiberg Island

i. Oil Terminal (same as Melville Island)	$9,200,000
ii. Sulphur Terminal	
Freight dock	200,000
Moorings	150,000
Conveyors	600,000
Shiploaders (2)	1,500,000
Site preparation	1,000,000
Electrical	500,000
Mobile Equipment	300,000
Bubbler system	1,000,000
Engineering and contingencies	750,000
	$6,000,000

iii. Combined Oil/Sulphur Terminal

Dock	$4,000,000
Mechanical and electrical	2,500,000
Bubbler System	1,500,000
Conveyors	600,000
Shiploaders (2) sulphur	1,500,000
Site preparation	1,000,000
Mobile Equipment	300,000
Engineering and Contingencies	1,600,000
	$13,000,000

Cost of Mooring Terminals ./.

The costs associated with an oil terminal include the dock and mooring facilities, loading arms, piping, controls on the dock and bubbler system. Excluded are the costs of the pipeline from shore and the shore-based storage tanks.

The costs associated with a dry bulk material shipping terminal include the mooring facilities, site preparation, rock-fill causeway or rock-cut (depending on topography of site), shiploader (s), conveying equipment, storage building if necessary (not necessary for iron ore and probably not necessary for sulphur), power generation and mobile equipment for terminal operation. Rock islands, if required, involve additional costs.

Cost of Single Buoy Mooring - (SBM)

A SBM of structural steel 30 feet in diameter and 15 feet in height, with all hose connections, controls, mooring cables, and anchors, would cost about $750,000 installed. This does not include de-icing equipment, pneumatic bubbler system, or pipeline to the shore.

Cost of Rock Islands

A program to study the optimum geometry for rock islands should be initiated. An example of cost differentials

based upon the size of rock island is as follows:

i. A rock island with a surface diameter of 200 feet and 20 feet above water level requires 430,000 cubic yards if the island were built in water 85 feet deep. Depending upon distance from rock source and sea conditions during construction, one island would cost from $1,000,000 to $5,000,000.

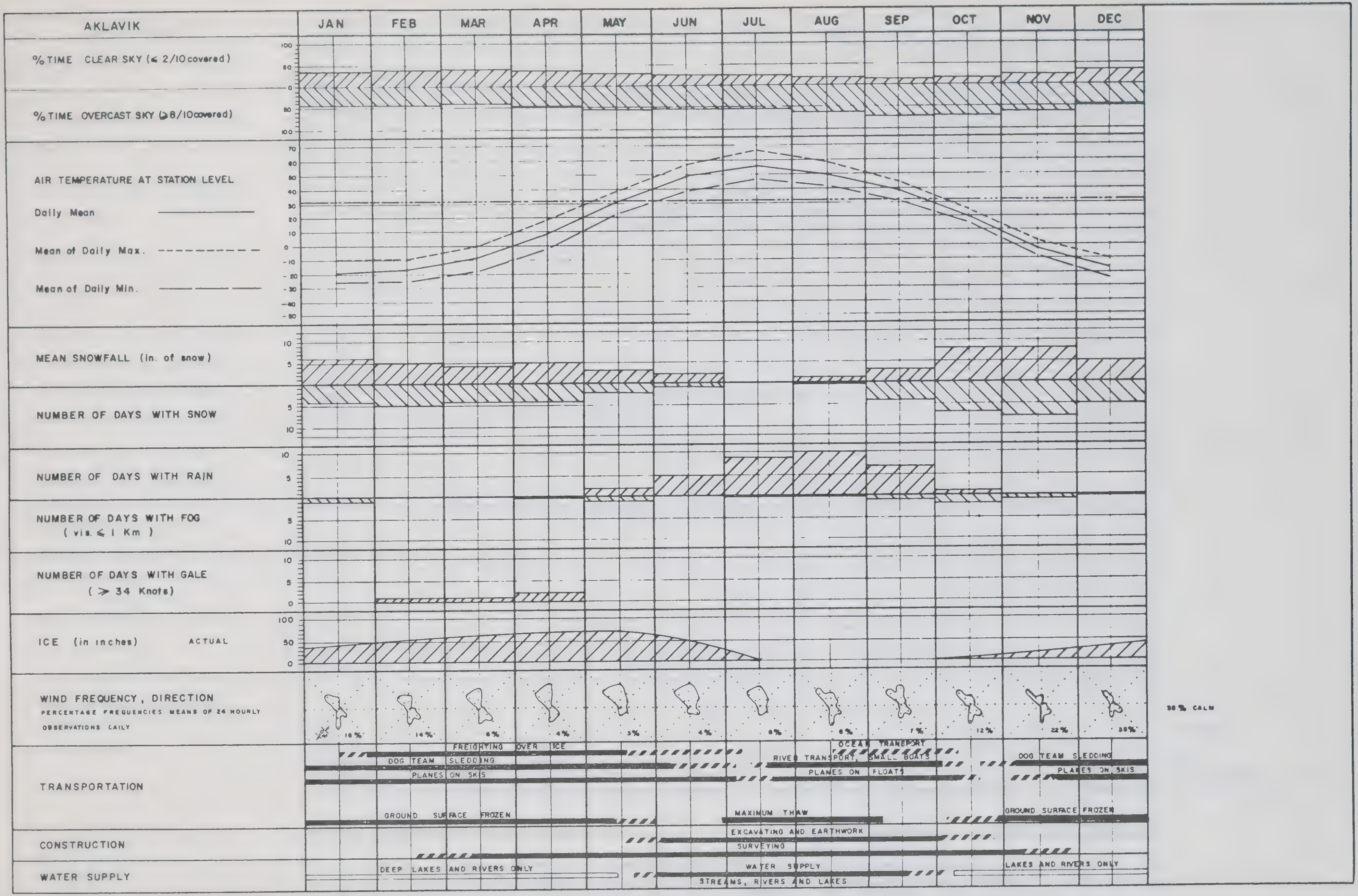
ii. A rock island with a surface diameter of 50 feet and 15 feet above water level requires 140,000 cubic yards if the island were again built in a depth of water of 85 feet. The cost of a single island would then be between $350,000 and $1,700,000.

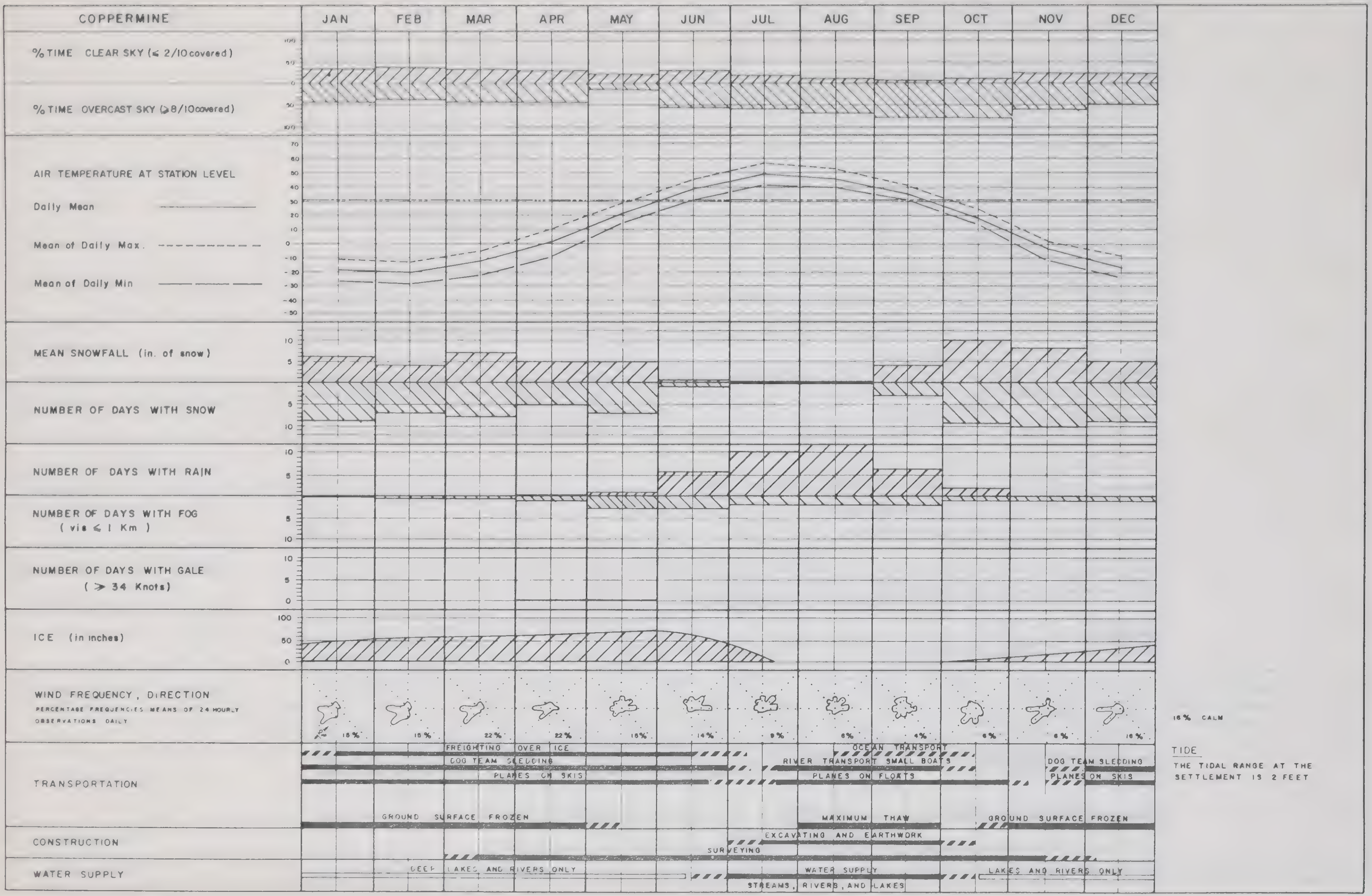
Rock Islands, in any number, would only be feasible if the rock were readily available close to the proposed terminal. The number of islands required must also be determined after extensive data collection on sea, ice, current and wind conditions.

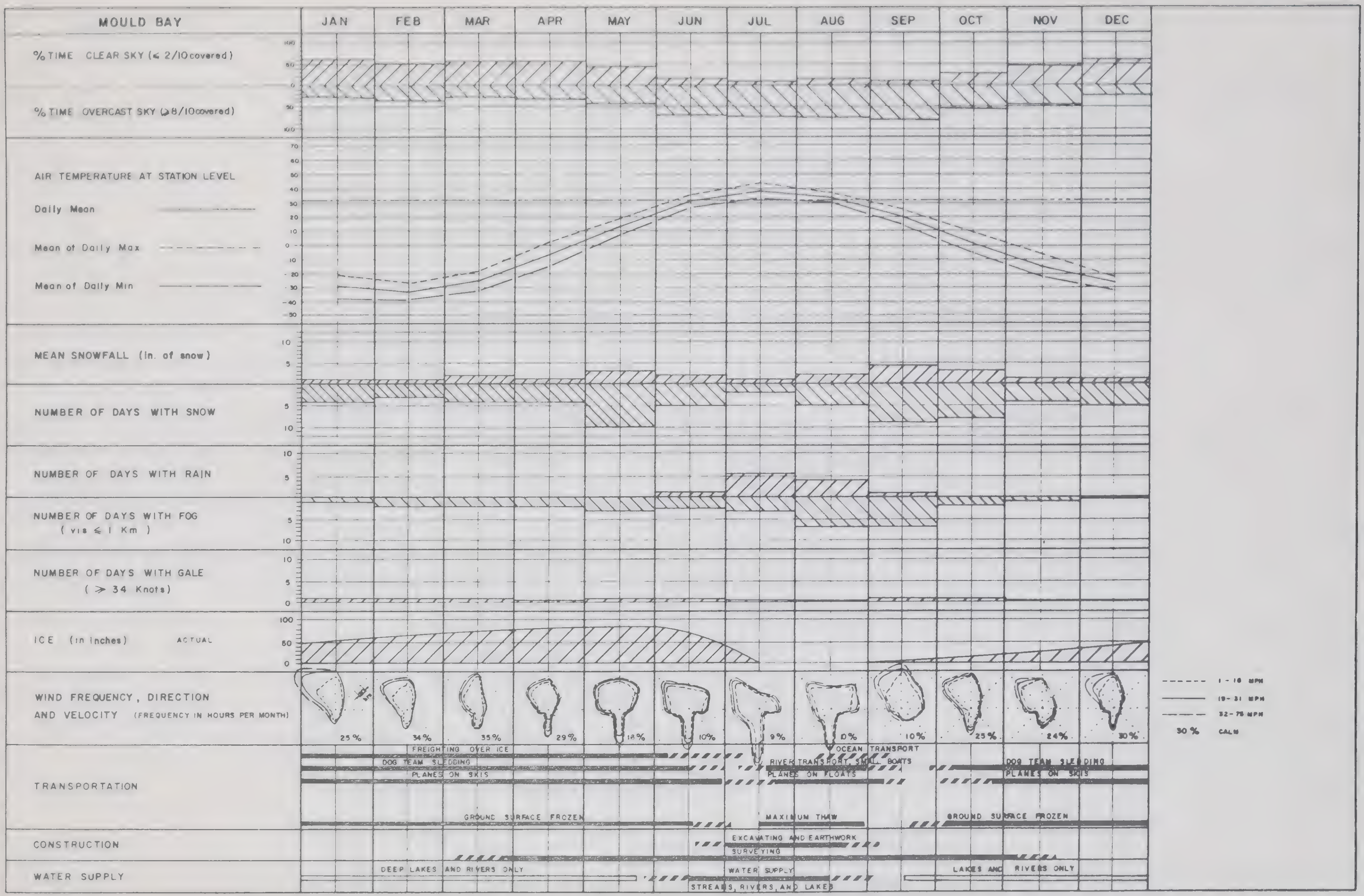
Appendices
index

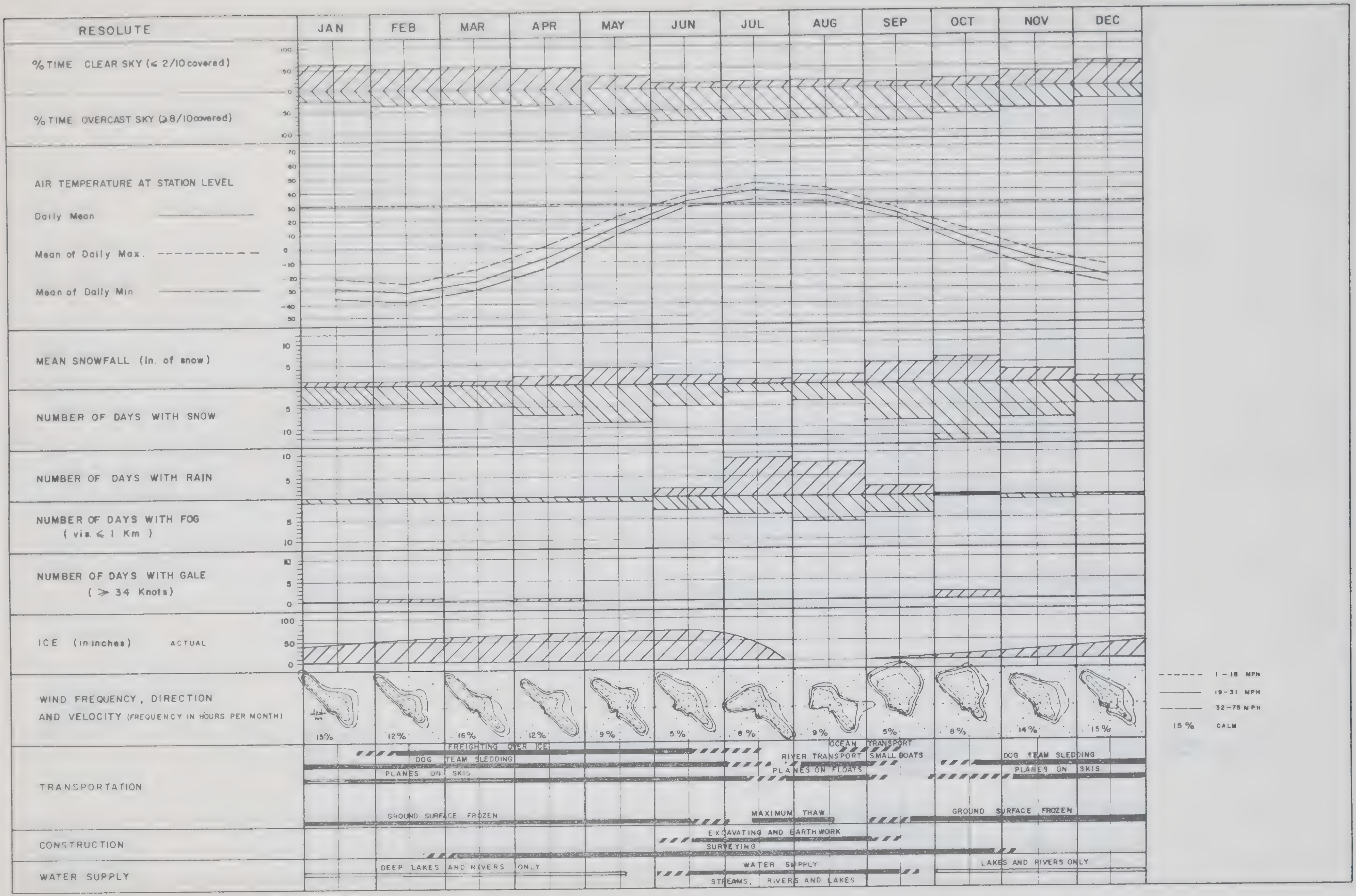
APPENDICES INDEX

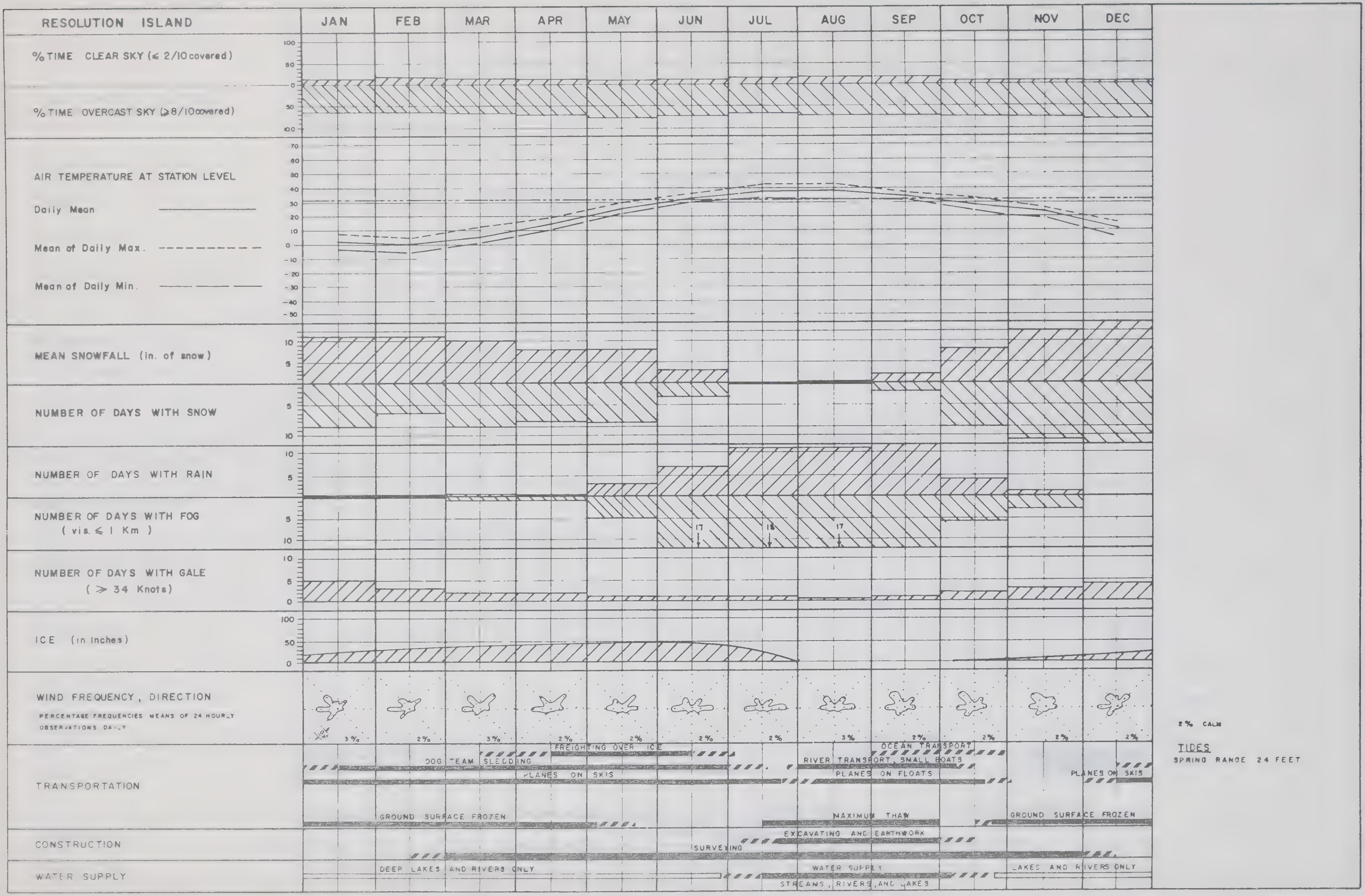
APPENDIX 1


AKLAVIK
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
% TIME CLEAR SKY (≤ 2/10 covered)
% TIME OVERCAST SKY (≥ 8/10 covered)
AIR TEMPERATURE AT STATION LEVEL
Daily Mean
Mean of Daily Max.
Mean of Daily Min.
MEAN SNOWFALL (in. of snow)
NUMBER OF DAYS WITH SNOW
NUMBER OF DAYS WITH RAIN
NUMBER OF DAYS WITH FOG (vis. ≤ 1 Km)
NUMBER OF DAYS WITH GALE (> 34 Knots)
ICE (in inches) ACTUAL
WIND FREQUENCY, DIRECTION
PERCENTAGE FREQUENCIES MEANS OF 24 HOURLY OBSERVATIONS DAILY
16% 14% 6% 4% 3% 4% 6% 6% 7% 12% 22% 38%
38% CALM
TRANSPORTATION
FREIGHTING OVER ICE
DOG TEAM SLEDDING
PLANES ON SKIS
OCEAN TRANSPORT
RIVER TRANSPORT, SMALL BOATS
PLANES ON FLOATS
DOG TEAM SLEDDING
PLANES ON SKIS
GROUND SURFACE FROZEN
MAXIMUM THAW
GROUND SURFACE FROZEN
CONSTRUCTION
EXCAVATING AND EARTHWORK
SURVEYING
WATER SUPPLY
DEEP LAKES AND RIVERS ONLY
WATER SUPPLY
STREAMS, RIVERS AND LAKES
LAKES AND RIVERS ONLY

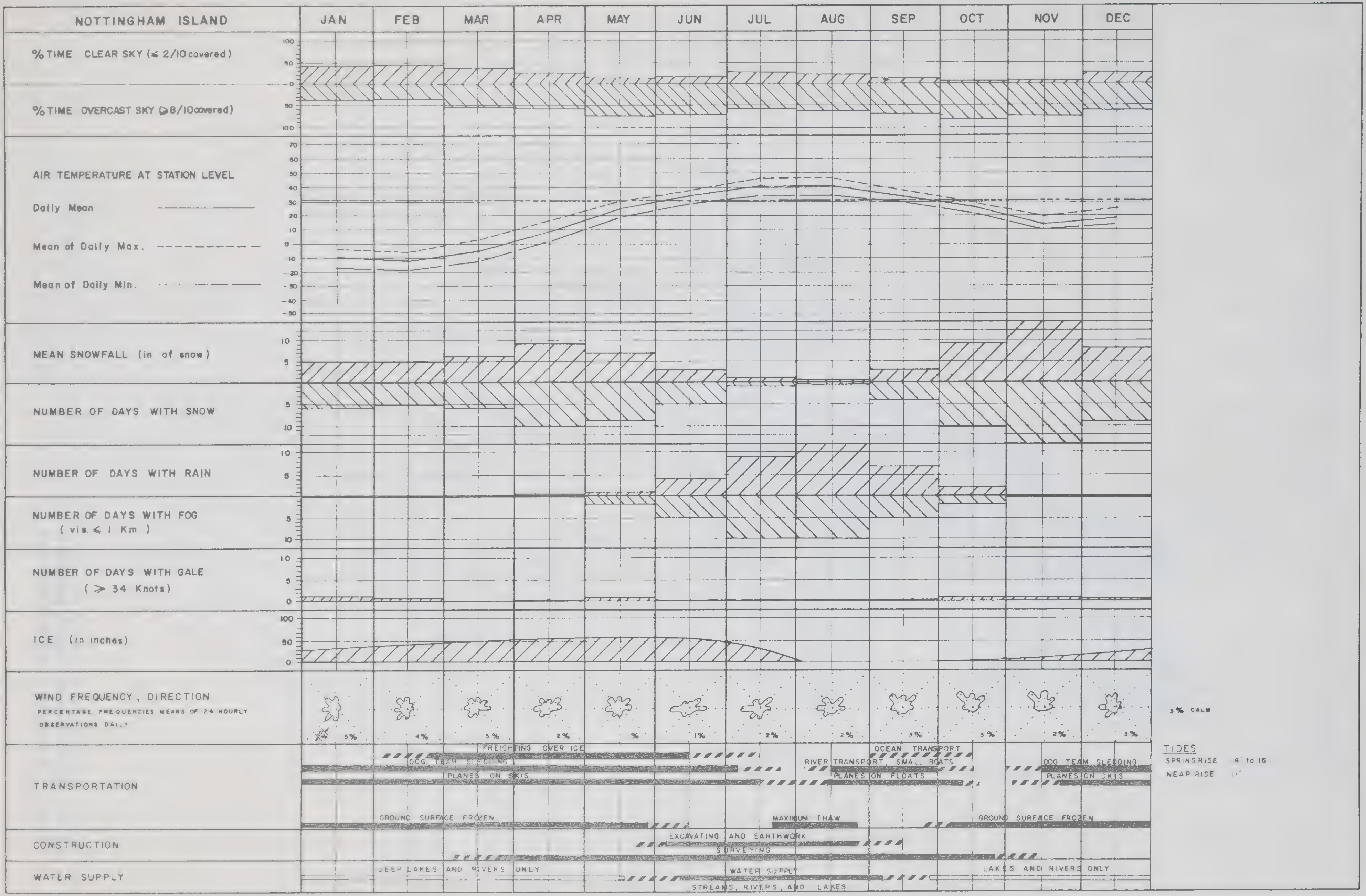

COPPERMINE
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
% TIME CLEAR SKY (≤ 2/10 covered)
% TIME OVERCAST SKY (≥ 8/10 covered)
AIR TEMPERATURE AT STATION LEVEL
Daily Mean
Mean of Daily Max.
Mean of Daily Min
MEAN SNOWFALL (in. of snow)
NUMBER OF DAYS WITH SNOW
NUMBER OF DAYS WITH RAIN
NUMBER OF DAYS WITH FOG
(vis ≤ 1 Km)
NUMBER OF DAYS WITH GALE
(≥ 34 Knots)
ICE (in inches)
WIND FREQUENCY, DIRECTION
PERCENTAGE FREQUENCIES MEANS OF 24 HOURLY OBSERVATIONS DAILY
18%
15%
22%
22%
15%
14%
9%
6%
4%
6%
6%
16%
16% CALM
TRANSPORTATION
FREIGHTING OVER ICE
DOG TEAM SLEDDING
PLANES ON SKIS
OCEAN TRANSPORT
RIVER TRANSPORT SMALL BOATS
PLANES ON FLOATS
DOG TEAM SLEDDING
PLANES ON SKIS
GROUND SURFACE FROZEN
MAXIMUM THAW
GROUND SURFACE FROZEN
CONSTRUCTION
EXCAVATING AND EARTHWORK
SURVEYING
WATER SUPPLY
DEEP LAKES AND RIVERS ONLY
WATER SUPPLY
STREAMS, RIVERS, AND LAKES
LAKES AND RIVERS ONLY
TIDE
THE TIDAL RANGE AT THE SETTLEMENT IS 2 FEET


MOULD BAY
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
% TIME CLEAR SKY (≤ 2/10 covered)
% TIME OVERCAST SKY (≥ 8/10 covered)
AIR TEMPERATURE AT STATION LEVEL
Daily Mean
Mean of Daily Max
Mean of Daily Min
MEAN SNOWFALL (in. of snow)
NUMBER OF DAYS WITH SNOW
NUMBER OF DAYS WITH RAIN
NUMBER OF DAYS WITH FOG (vis ≤ 1 Km)
NUMBER OF DAYS WITH GALE (≥ 34 Knots)
ICE (in inches) ACTUAL
WIND FREQUENCY, DIRECTION AND VELOCITY (FREQUENCY IN HOURS PER MONTH)
25% 34% 35% 29% 18% 10% 9% 0% 10% 25% 24% 30%
1 - 18 MPH
19 - 31 MPH
32 - 75 MPH
30 % CALM
TRANSPORTATION
FREIGHTING OVER ICE
DOG TEAM SLEDDING
PLANES ON SKIS
OCEAN TRANSPORT
RIVER TRANSPORT SMALL BOATS
PLANES ON FLOATS
DOG TEAM SLEDDING
PLANES ON SKIS
GROUND SURFACE FROZEN
MAXIMUM THAW
GROUND SURFACE FROZEN
CONSTRUCTION
EXCAVATING AND EARTHWORK
SURVEYING
WATER SUPPLY
DEEP LAKES AND RIVERS ONLY
WATER SUPPLY
STREAMS, RIVERS, AND LAKES
LAKES AND RIVERS ONLY

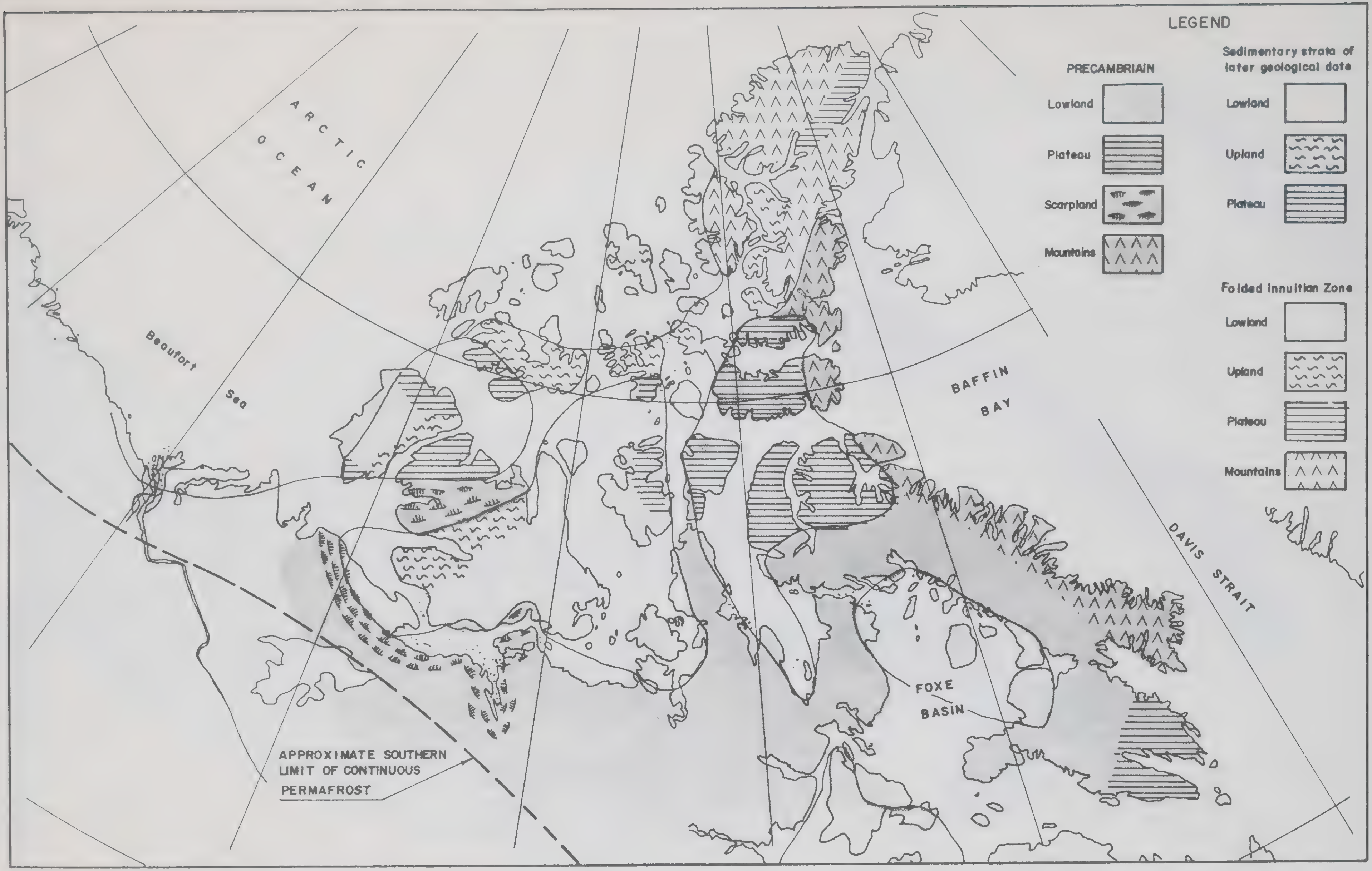

RESOLUTE
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
% TIME CLEAR SKY (≤ 2/10 covered)
% TIME OVERCAST SKY (≥ 8/10 covered)
AIR TEMPERATURE AT STATION LEVEL
Daily Mean
Mean of Daily Max.
Mean of Daily Min
MEAN SNOWFALL (In. of snow)
NUMBER OF DAYS WITH SNOW
NUMBER OF DAYS WITH RAIN
NUMBER OF DAYS WITH FOG
(vis. ≤ 1 Km)
NUMBER OF DAYS WITH GALE
(> 34 Knots)
ICE (in inches) ACTUAL
WIND FREQUENCY, DIRECTION
AND VELOCITY (FREQUENCY IN HOURS PER MONTH)
15%
12%
16%
12%
9%
5%
8%
9%
5%
8%
14%
15%
1 – 18 MPH
19 – 31 MPH
32 – 75 MPH
15% CALM
TRANSPORTATION
FREIGHTING OVER ICE
DOG TEAM SLEDDING
PLANES ON SKIS
OCEAN TRANSPORT
RIVER TRANSPORT SMALL BOATS
PLANES ON FLOATS
DOG TEAM SLEDDING
PLANES ON SKIS
GROUND SURFACE FROZEN
MAXIMUM THAW
GROUND SURFACE FROZEN
CONSTRUCTION
EXCAVATING AND EARTHWORK
SURVEYING
WATER SUPPLY
DEEP LAKES AND RIVERS ONLY
WATER SUPPLY
STREAMS, RIVERS AND LAKES
LAKES AND RIVERS ONLY



RESOLUTION ISLAND
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
% TIME CLEAR SKY (≤ 2/10 covered)
% TIME OVERCAST SKY (≥ 8/10 covered)
AIR TEMPERATURE AT STATION LEVEL
Daily Mean
Mean of Daily Max.
Mean of Daily Min.
MEAN SNOWFALL (in. of snow)
NUMBER OF DAYS WITH SNOW
NUMBER OF DAYS WITH RAIN
NUMBER OF DAYS WITH FOG
(vis. ≤ 1 Km)
NUMBER OF DAYS WITH GALE
(> 34 Knots)
ICE (in Inches)
WIND FREQUENCY, DIRECTION
PERCENTAGE FREQUENCIES MEANS OF 24 HOURLY OBSERVATIONS DAILY
3% 2% 3% 2% 2% 2% 2% 3% 2% 2% 2% 2%
2% CALM
TRANSPORTATION
DOG TEAM SLEDDING
FREIGHTING OVER ICE
PLANES ON SKIS
RIVER TRANSPORT, SMALL BOATS
OCEAN TRANSPORT
PLANES ON FLOATS
PLANES ON SKIS
CONSTRUCTION
GROUND SURFACE FROZEN
MAXIMUM THAW
GROUND SURFACE FROZEN
EXCAVATING AND EARTHWORK
SURVEYING
WATER SUPPLY
DEEP LAKES AND RIVERS ONLY
WATER SUPPLY
STREAMS, RIVERS, AND LAKES
LAKES AND RIVERS ONLY
TIDES
SPRING RANGE 24 FEET

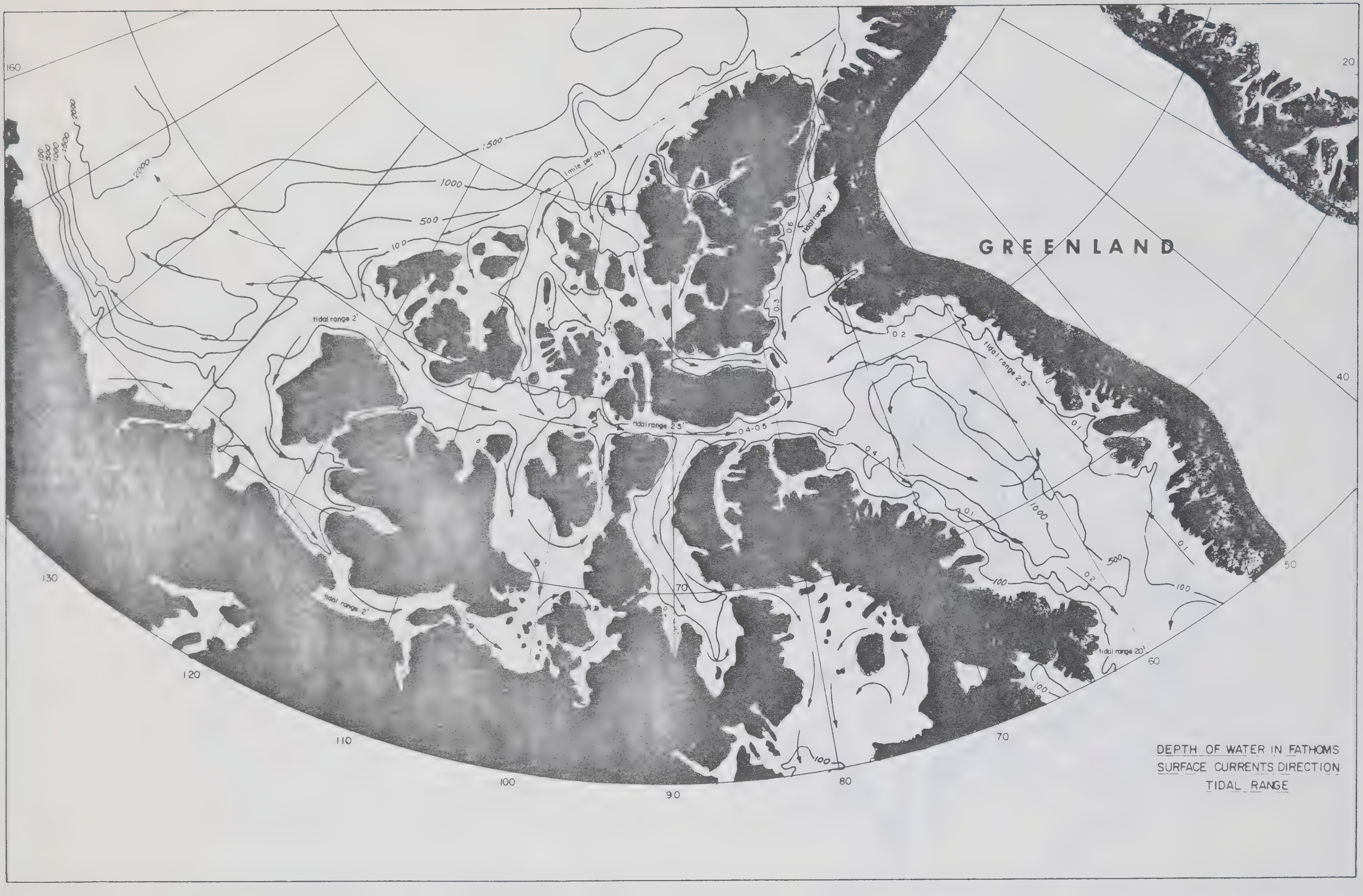

NOTTINGHAM ISLAND
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
% TIME CLEAR SKY (≤ 2/10 covered)
% TIME OVERCAST SKY (≥8/10 covered)
AIR TEMPERATURE AT STATION LEVEL
Daily Mean
Mean of Daily Max.
Mean of Daily Min.
MEAN SNOWFALL (in of snow)
NUMBER OF DAYS WITH SNOW
NUMBER OF DAYS WITH RAIN
NUMBER OF DAYS WITH FOG
(vis. ≤ 1 Km)
NUMBER OF DAYS WITH GALE
(≥ 34 Knots)
ICE (in inches)
WIND FREQUENCY, DIRECTION
PERCENTAGE FREQUENCIES MEANS OF 24 HOURLY OBSERVATIONS DAILY
5%
4%
5%
2%
1%
1%
2%
2%
3%
3%
2%
3%
3% CALM
TRANSPORTATION
FREIGHTING OVER ICE
DOG TEAM SLEDDING
PLANES ON SKIS
RIVER TRANSPORT, SMALL BOATS
OCEAN TRANSPORT
PLANES ON FLOATS
DOG TEAM SLEDDING
PLANES ON SKIS
TIDES
SPRINGRISE 4' to 16'
NEAP RISE 11'
GROUND SURFACE FROZEN
MAXIMUM THAW
GROUND SURFACE FROZEN
CONSTRUCTION
EXCAVATING AND EARTHWORK
SURVEYING
WATER SUPPLY
DEEP LAKES AND RIVERS ONLY
WATER SUPPLY
STREAMS, RIVERS, AND LAKES
LAKES AND RIVERS ONLY

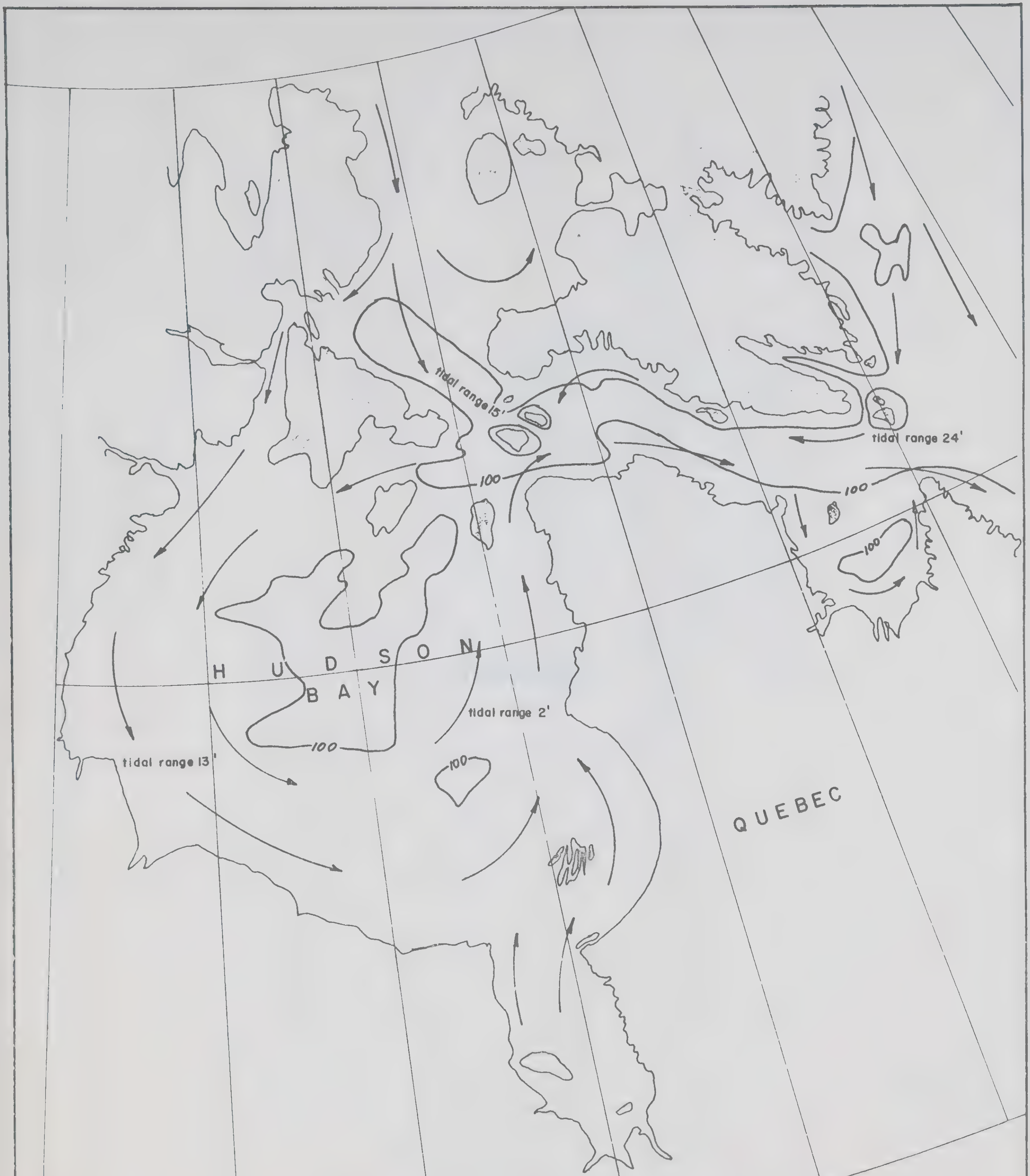
APPENDIX 11



PHYSIOGRAPHY OF THE CANADIAN ARCTIC

APPENDIX 111


GREENLAND
DEPTH OF WATER IN FATHOMS
SURFACE CURRENTS DIRECTION
TIDAL RANGE
1 mile per day
tidal range 7'
tidal range 2.5'
tidal range 20'
tidal range 2'
2000
1500
1000
500
100
0.4-0.5
160
130
120
110
100
90
80
70
60
50
40
20



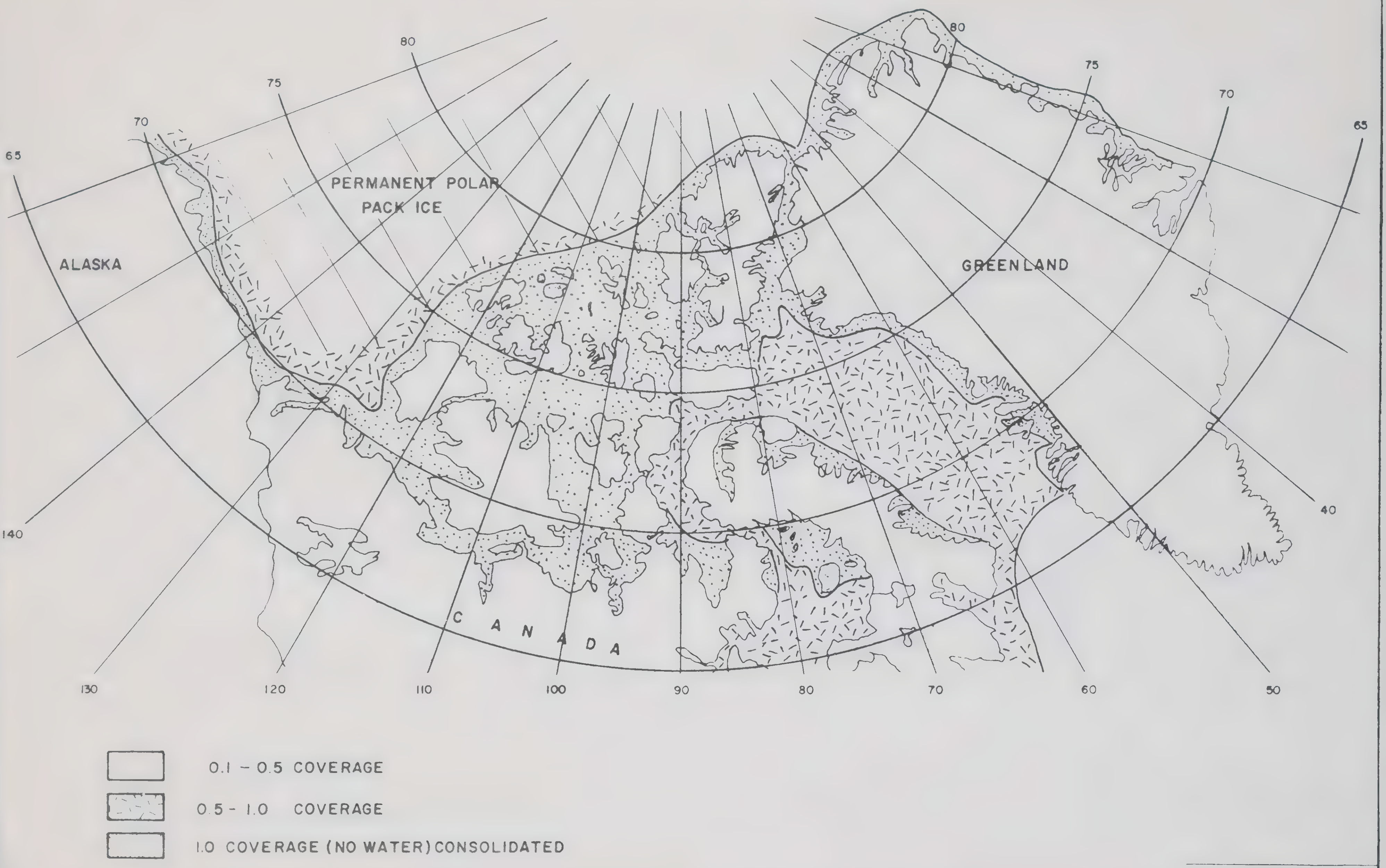
DEPTH OF WATER IN FATHOMS

SURFACE CURRENTS DIRECTION

TIDAL RANGE

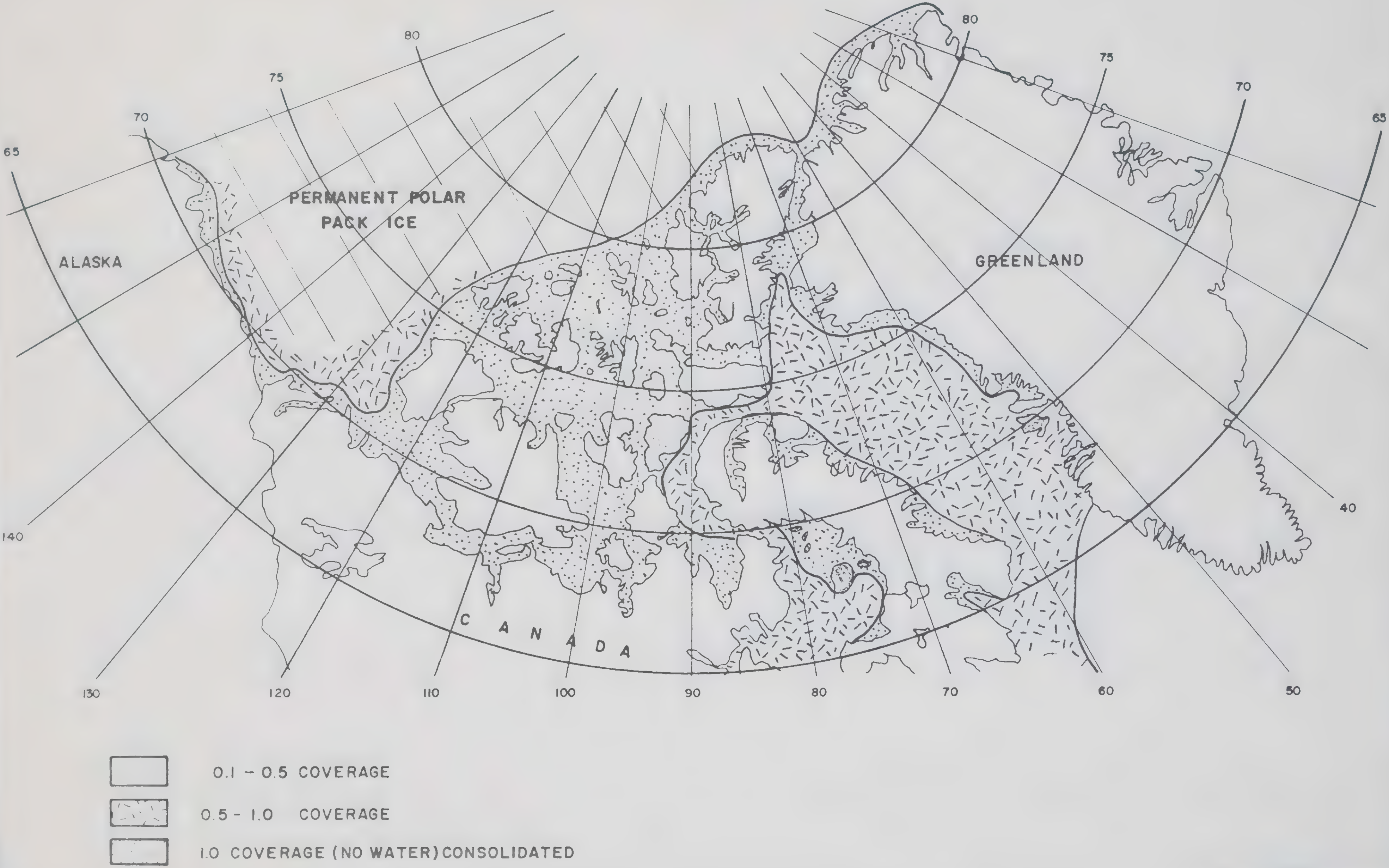
APPENDIX 1V

AVERAGE CONCENTRATION OF ICE CONDITIONS



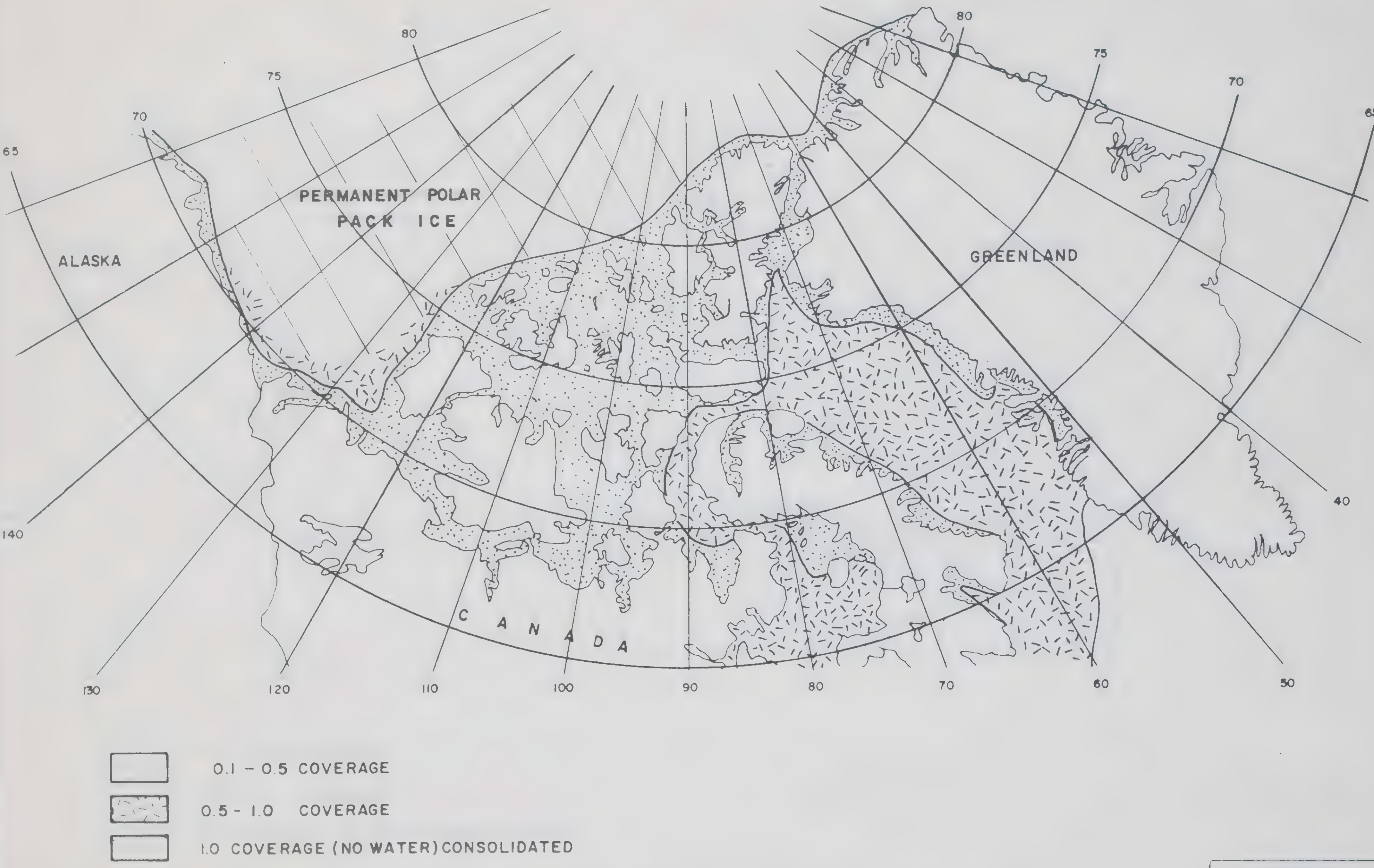
JANUARY

AVERAGE CONCENTRATION OF ICE CONDITIONS



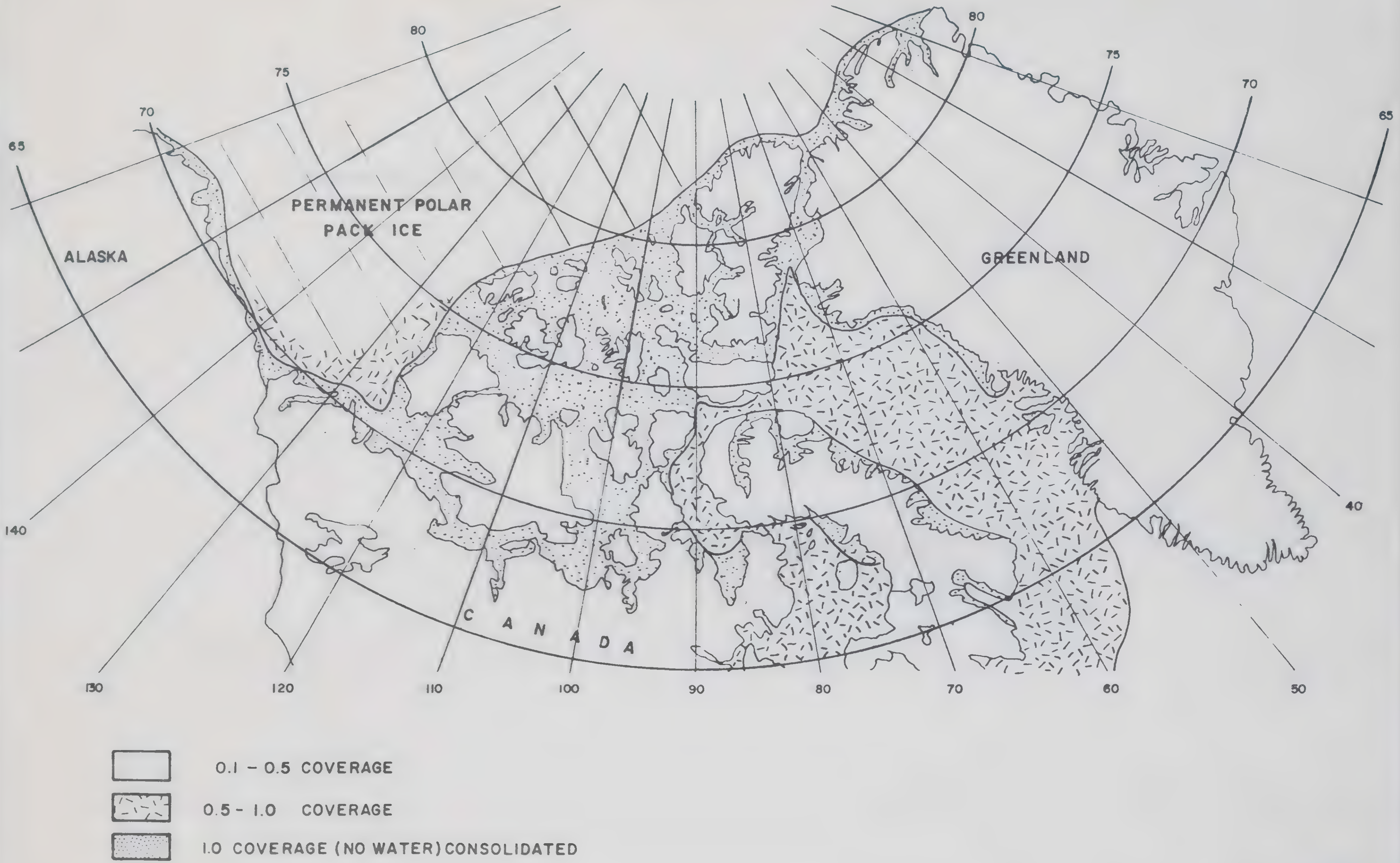
FEBRUARY

AVERAGE CONCENTRATION OF ICE CONDITIONS



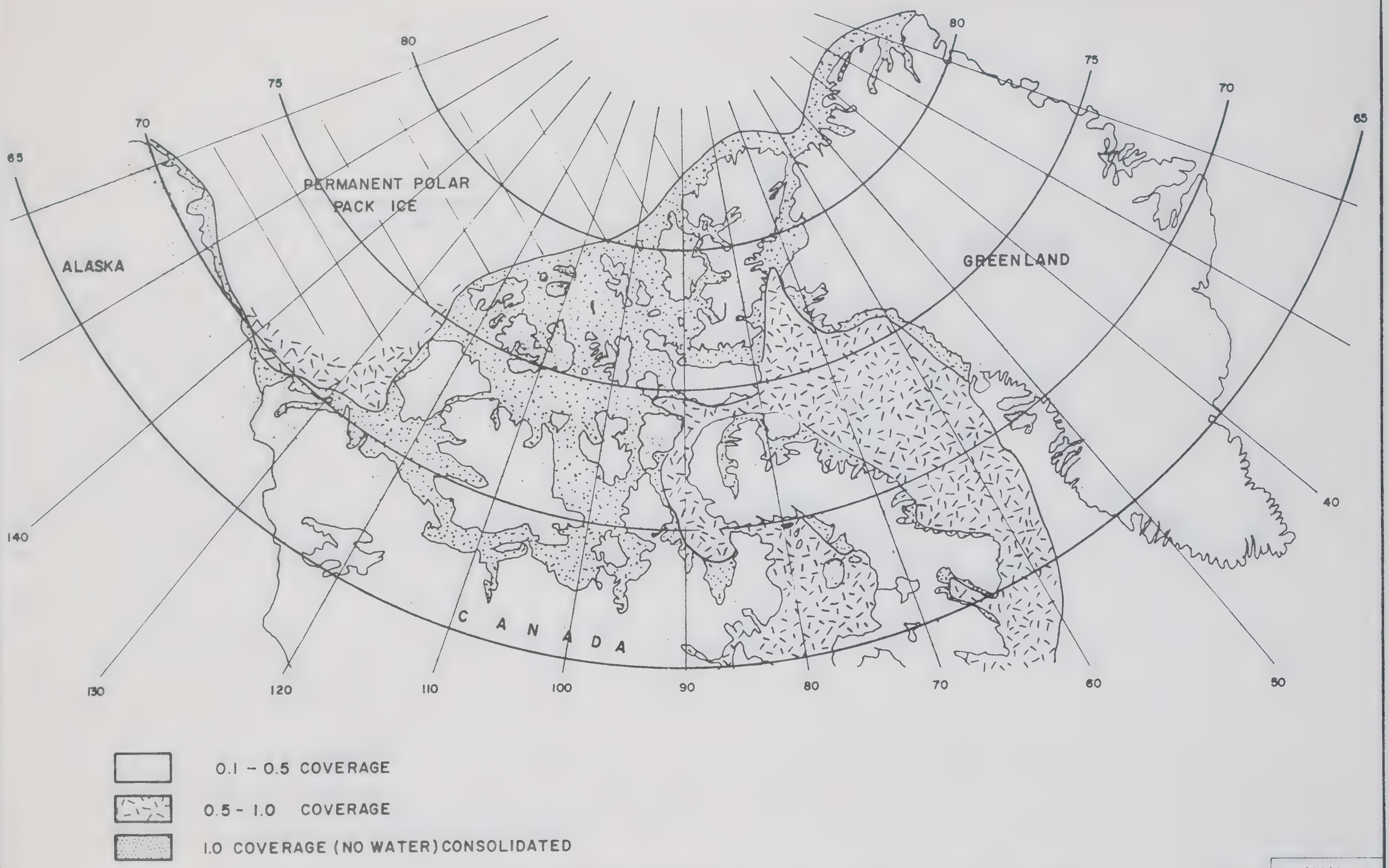
MARCH

AVERAGE CONCENTRATION OF ICE CONDITIONS



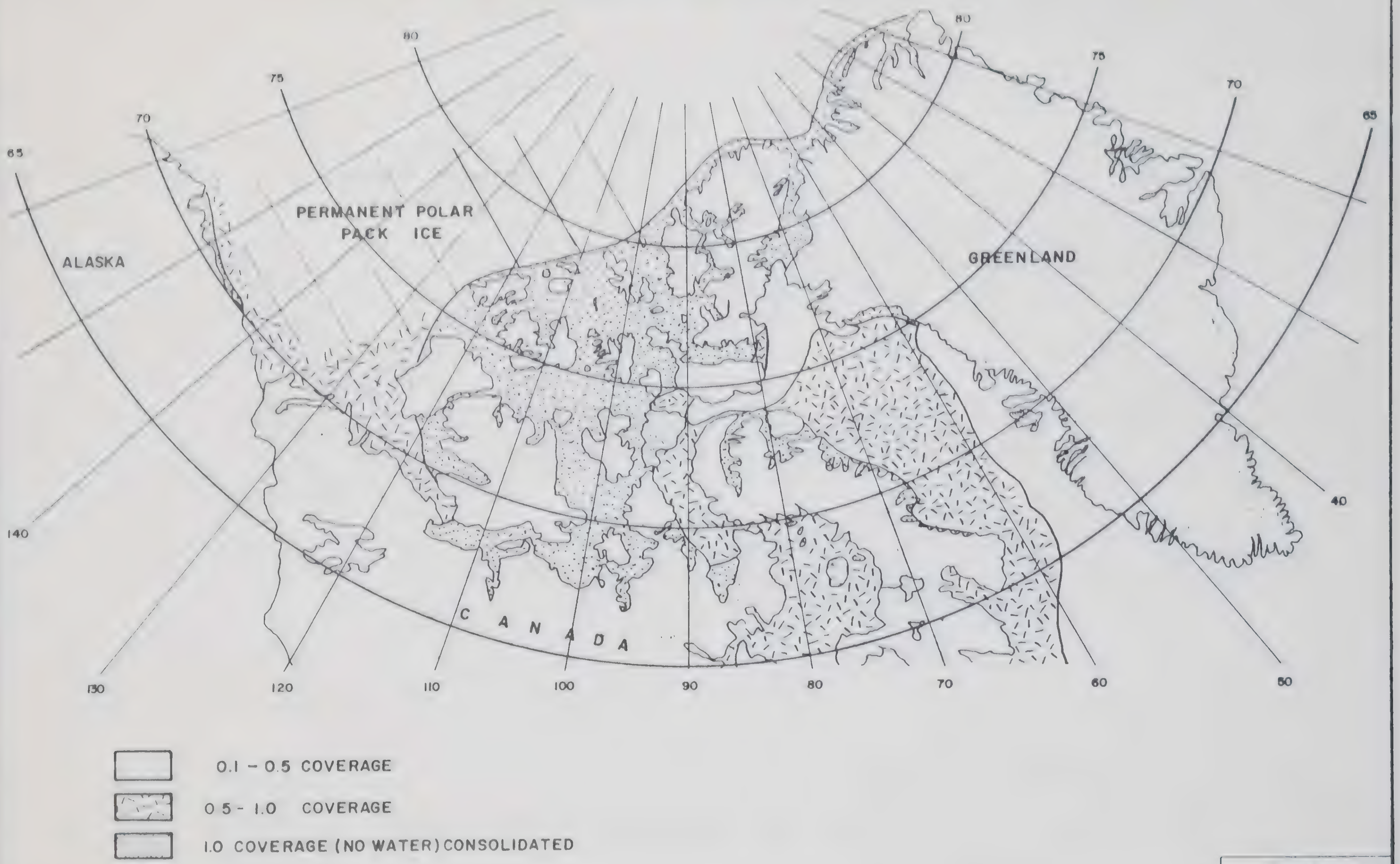
APRIL

AVERAGE CONCENTRATION OF ICE CONDITIONS



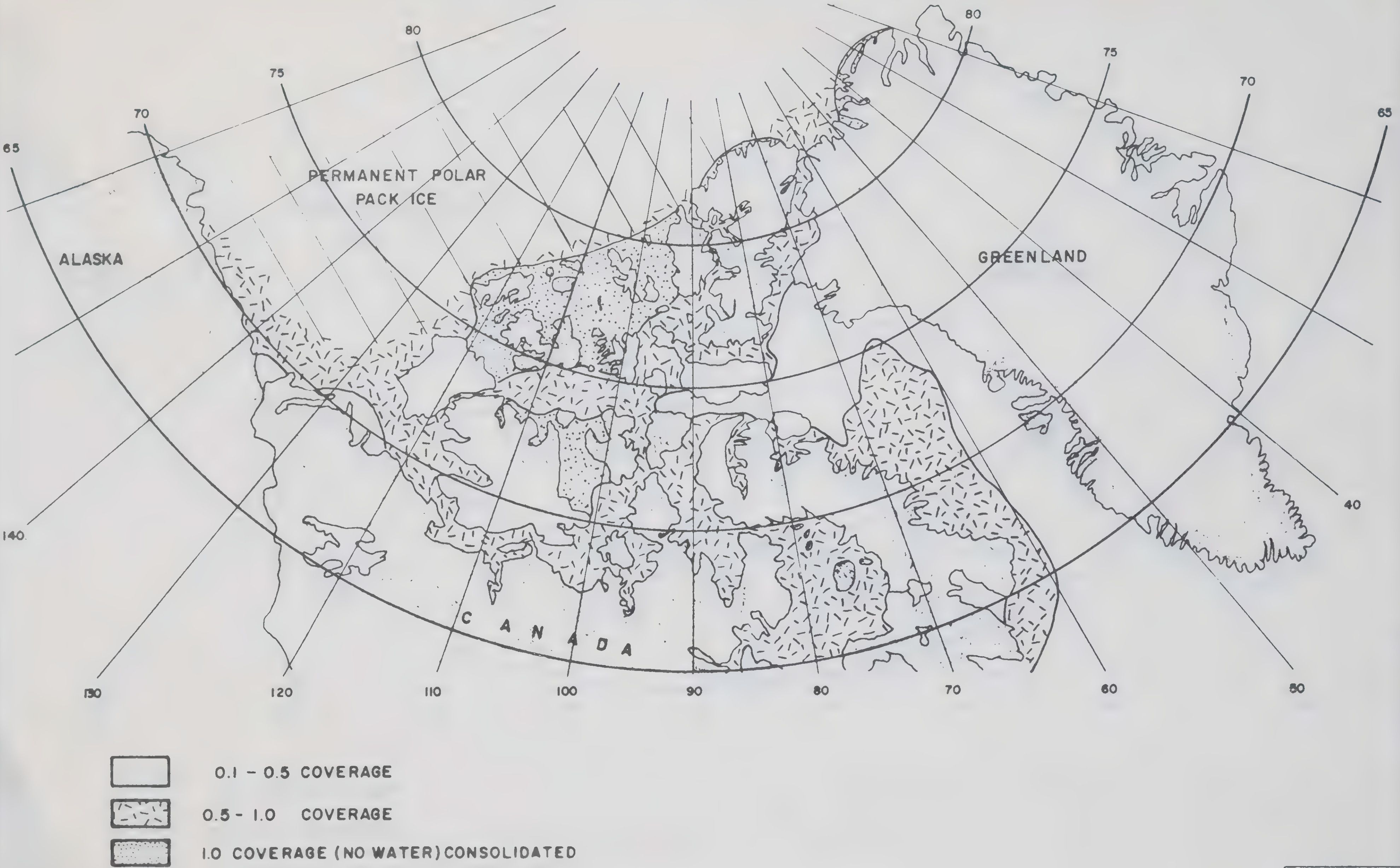
MAY

AVERAGE CONCENTRATION OF ICE CONDITIONS



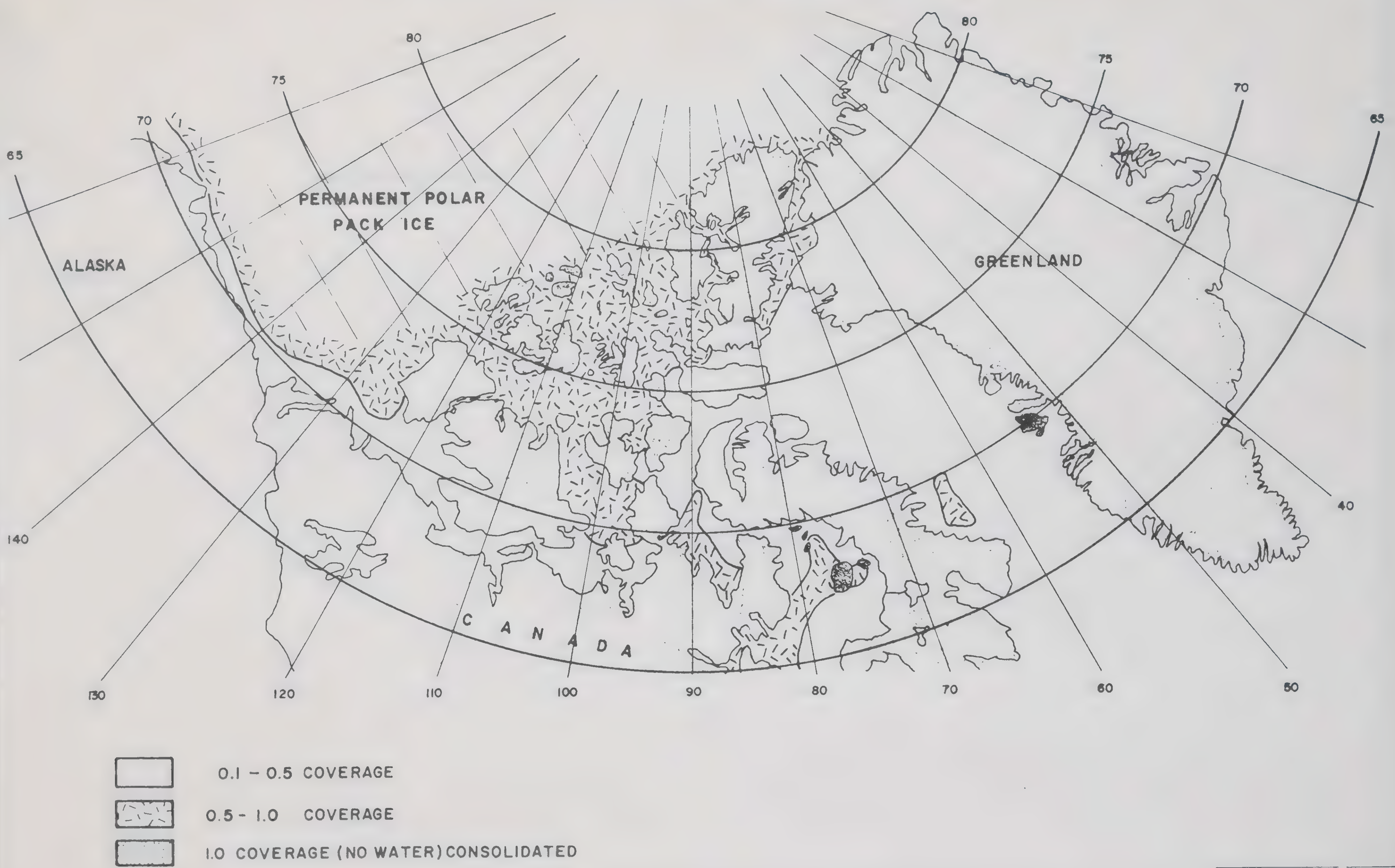
JUNE

AVERAGE CONCENTRATION OF ICE CONDITIONS



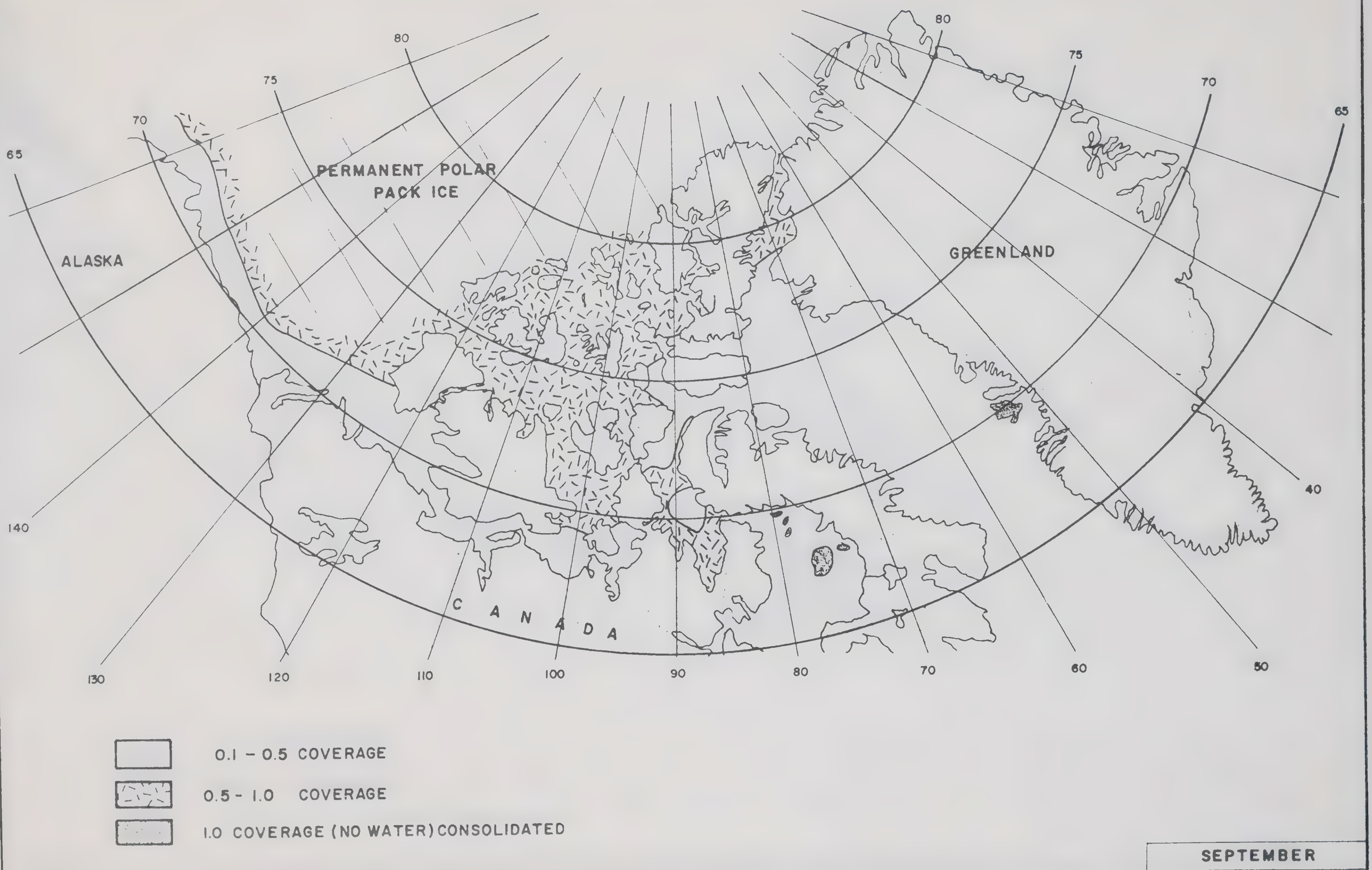
JULY

AVERAGE CONCENTRATION OF ICE CONDITIONS



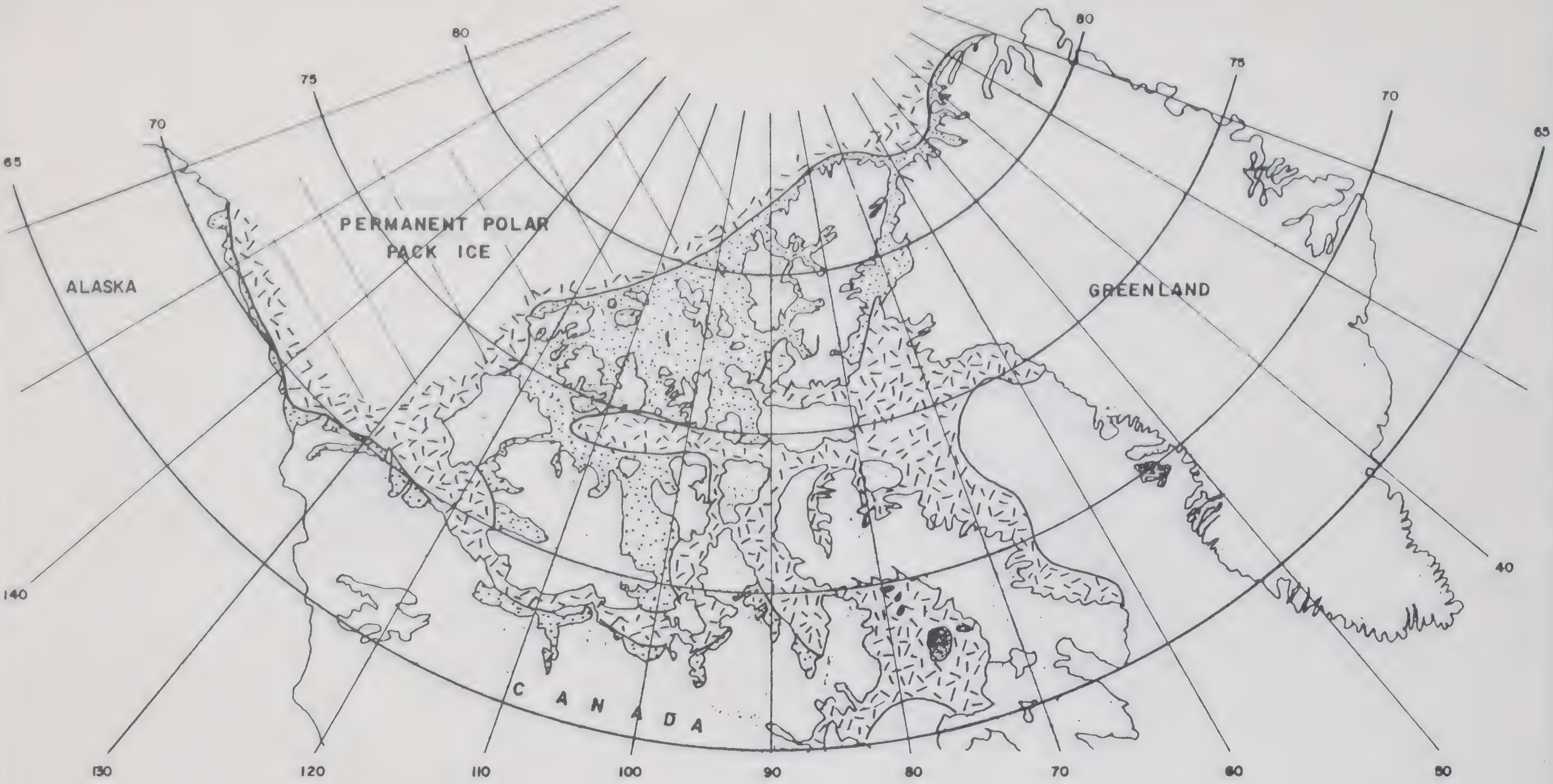
AUGUST

AVERAGE CONCENTRATION OF ICE CONDITIONS



SEPTEMBER

AVERAGE CONCENTRATION OF ICE CONDITIONS



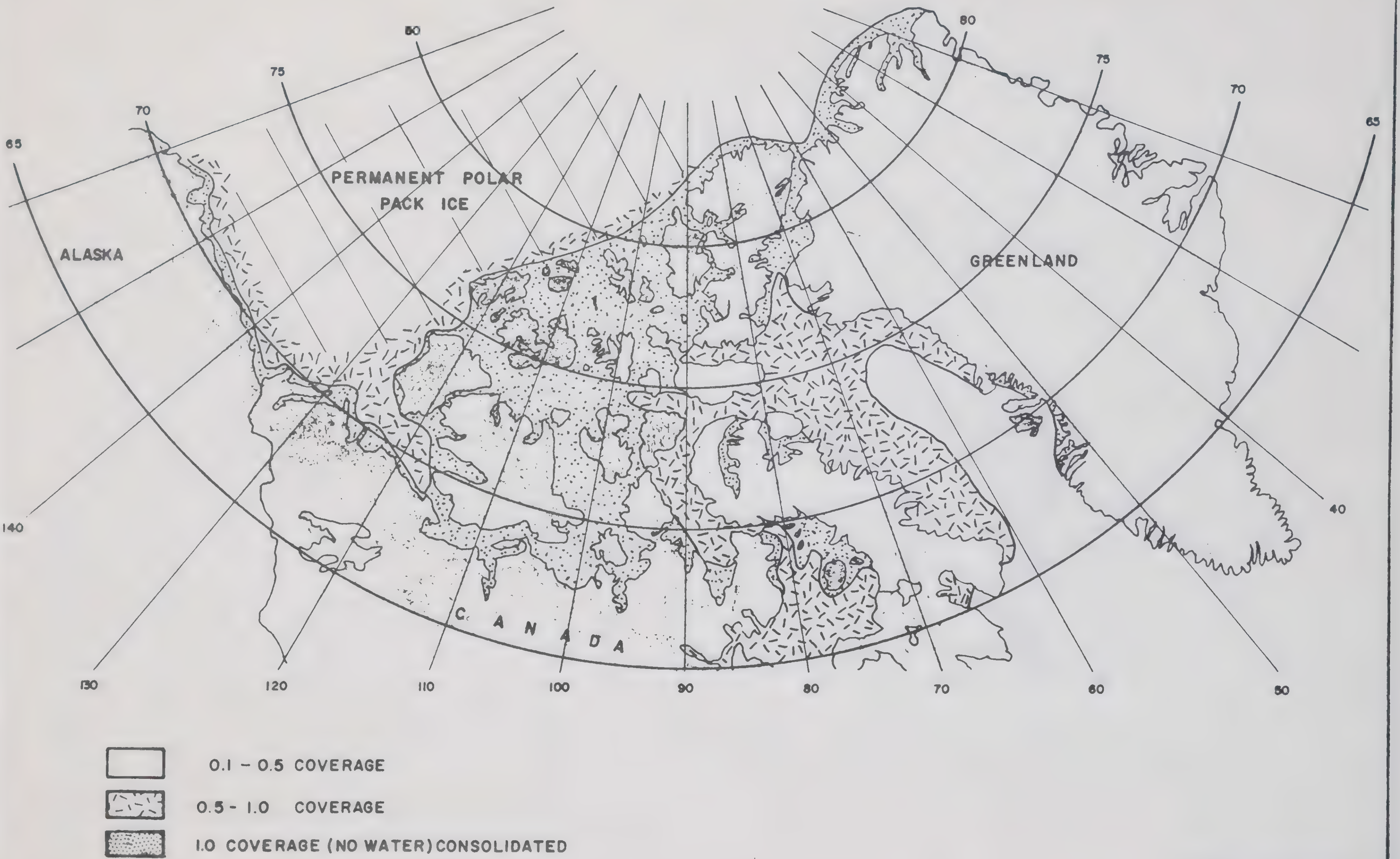
0.1 – 0.5 COVERAGE

0.5 - 1.0 COVERAGE

1.0 COVERAGE (NO WATER) CONSOLIDATED

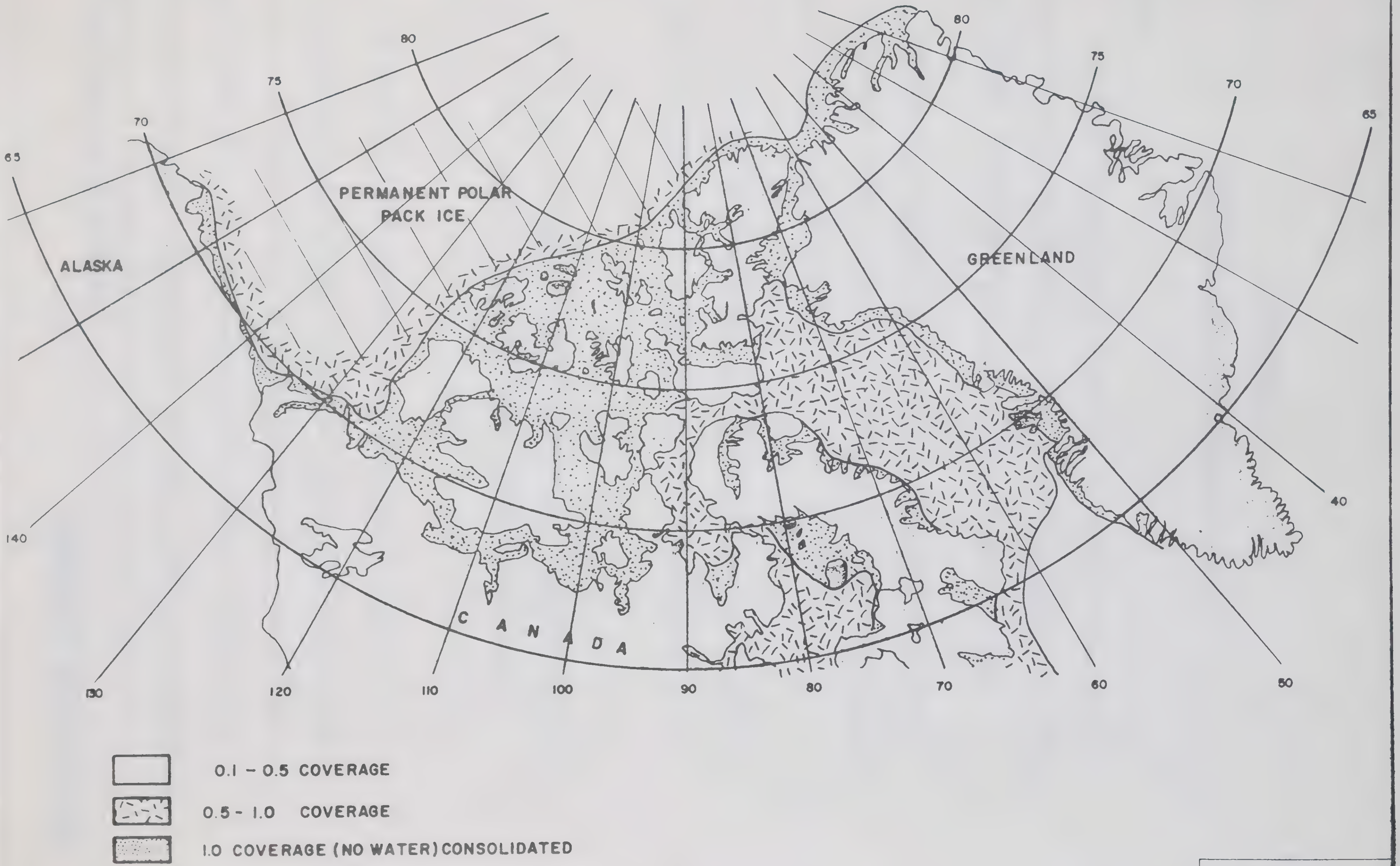
OCTOBER

AVERAGE CONCENTRATION OF ICE CONDITIONS



NOVEMBER

AVERAGE CONCENTRATION OF ICE CONDITIONS



DECEMBER

APPENDIX V

Lloyd's Register of Shipping Ice Class 1*

FRAMING

2403 The frame spacing is not, in general, to exceed 610 mm (24 in) between the forward perpendicular and. 25L forward of amidships and 800 mm (31.5 in) over the remainder of the length to the after peak bulkhead.

2404 Intermediate frames are to be fitted over the full length of the ship. The strength of these frames is to be the same as that of the adjacent rule main or 'tween deck frames.

In way of deep tanks the section modulus of intermediate frames may be that of the main frames before the increase required by D 721 is applied.

In the panting region clear of deep tanks the intermediate frames may have a section modulus as derived from D 708 (b) but ignoring the factor f.

The intermediate frames are to extend from the upper deck, or from the second deck provided this is at least 750 mm (29.5 in) above the load waterline, to below the level of the top of floors or to a point just above the tank top where this runs horizontally to the ship's side, and need not be connected at their ends. Where the second deck is above the load waterline

* Lloyd's Register of Shipping Rules and Regulations for the Construction and Classification of Steel Ships.

but less than 750 mm (29.5 in) above, the intermediate frames may terminate at a stringer situated not less than 1,2 m (4 ft) above the load waterline.

In the fore and aft peaks the main and intermediate frames are to have the same modulus as an amidship frame determined from D 708 (a) with a frame spacing equal to $\frac{L_1}{50} + 510$ mm $\left(\frac{L_1}{50} + 20 \text{ in.}\right)$ or a modulus equal to twice that of the normal peak frames whichever is the greater.

Where the frames terminate at the 2nd deck, and long or broad hatchways are fitted in this deck, the plating in way of the hatchways is to be suitably strengthened by fitting web frames or strong beams to give adequate support to the framing.

2405 Intermediate frames are to be fitted over the full length of the ship. The strength of these frames is to be the same as that of the adjacent Rule main or 'tween deck frames, unless stringers are fitted in accordance with 2429 when the intermediate frames may be 75 per cent of the adjacent Rule frames.

In way of deep tanks the section modulus of intermediate frames may be that of the main frames before the increase required by D 721 is applied.

Appendix V . /.

In the panting region clear of deep tanks the intermediate frames may have a section modulus as derived from D708 (b) but ignoring the factor f.

The intermediate frames are to extend from 915 mm (36 in) below the light waterline to 750 mm (29.5 in) above the load waterline. They are to be connected at their ends to the adjacent frames by a horizontal member having the same scantlings as these frames, or equivalent arrangements are to be provided. Alternatively, they are to be carried down to within 255 mm (10 in) of the margin plate or, where the ship has no double bottom, to a point below the top of the floors. If the frames are so extended they need not be attached at the lower end.

In the fore and aft peaks the main and intermediate frames are to have the same modulus as an amidship frame determined from D 708 (a) with a frame spacing equal to $\frac{L_l}{0,6} + 510$ mm $\left(\frac{L_l}{50} + 20 \text{ in}\right)$, or a modulus equal to twice that of the normal peak frames, whichever is the greater.

SHELL PLATING

2410 From the forward perpendicular aft for a length equal to the distance from the forward perpendicular to the point where the load waterline reaches its greatest breadth plus 10 per cent of that distance, and extending vertically from 610 mm (24 in) below the light waterline to 750mm (29.5 in)

above the load waterline, the thickness of the shell plating is not to be less than 1,8 t_b mm (in) .

2411 From this position to 0, 25L aft of amidships and over the same vertical extent, the thickness of shell plating is not to be less than 1, 4t_b mm (in).

If the parallel middle portion on the load waterline extends further aft than 0, 25L aft of amidships, the shell plating over this parallel middle portion is also not to be less than 1, 4t_b mm (in).

2412 For the remainder of the length and over the same vertical extent, the thickness of shell plating is not to be less than 1, 25 t_b mm (in).

2413 The side and bottom shell plating below this belt from the stem to a position five frame spaces abaft the point where the bow profile departs from the level keel line is not to be less than 1, 8t_b mm(in).

2414 The increased thickness need not exceed 32 mm (1.25 in), but is not to be less than 14 mm (0. 55 in). Changes in thickness are to take place gradually.

2415 When the s.h.p. exceeds 2, 26 (L X B), or in British units 0. 21 (L X B), the shell plating for the longitudinal extent given in 2410 shall be

increased by a further 1 mm (0.04 in) for each 500 s.h.p. excess over the above figure, but need not exceed 32 mm (1.25 in). (The s.h.p. is to be indicated on the plan on which the shell plating is approved).

2416 For the longitudinal and vertical extent given in 2410 the thickness of the shell plating is not to be less than 1,5t_b mm (in).

2417 For the remainder of the length and over the same vertical extent the thickness of shell plating is not to be less than 1,25t_b mm (in).

2418 The increased thickness need not exceed 25,5 mm (1.00 in), but is not to be less than 12,5 mm (0.50 in) Changes in thickness are to take place gradually.

STRINGERS

2425 Forward of the collision bulkhead the tiers of beams and stringers required by D 11 are to be spaced not more than 1,3m (4.25 ft) apart.

2426 Abaft the collision bulkhead the stringer next below the load waterline is to be extended over the full length of the ship, unless a deck is situated not more than 1,2 m (4 ft) below the load waterline, and the main and intermediate frames are to be attached thereto.

The stringers immediately above and below this stringer are also to be extended over the full length of the ship, but may be intercostal and of the same scantlings as the frames in way.

2427 Where the light waterline lies well above the margin a stringer may be required in the vicinity of the light waterline and over the full length of the ship.

2428 In single deck ships a stringer is to be arranged in the vicinity of the load waterline, over the full length of the ship.

2429 The following requirements apply only when the intermediate frames are made 75 per cent of the adjacent Rule main or 'tween deck frames. See 2405.

Abaft the collision bulkhead stringers of the scantlings given in D11 are to be fitted 2 m (6.56 ft) apart for the longitudinal extent given in 2410.

2430 The stringer next below the load waterline is to be extended over the full length of the ship unless a deck is situated not more than 600 mm (23.5 in) below the load waterline, for Ice Class 1 only.

Appendix V ./.

RUDDER & STEERING ARRANGEMENTS

2433 The diameters of the rudder head and the pintles are to be increased above that required by D 22 by:-

Class 1 - 30 per cent.

2434 The side plating and webs of double plate rudders are to be increased above that required by D22 by:-

Class 1 - 50 percent.

2435 The gudgeons, remaining rudder items and couplings are to be based on the increased rudder head or pintle and the steering gear is to be suitably protected against,or designed to withstand, the increased loading.

In welded double plate rudders, the horizontal and vertical webs are not to be welded direct to the side plates, but are to be attached to flat bars or equivalent arrangement made to avoid hard points.

2436 The rudder head is to be protected by an ice knife, a suitable stern, or other equivalent arrangements - Ice Classes 1 only.

STERNFRAME

2437 The strength of the rudder horn, rudder post and solepiece and the diameter of the rudder axle (if fitted) are to be increased above the rule

requirements by:-

Class 1 - 30 per cent.

STEM

2438 The bow should be a form specially designed for navigation in ice, i. e. an ice-breaker type bow should be fitted.

A solid stem of forged, rolled, or cast steel is to be fitted up to 750 mm (29.5 in) above the load waterline.

2439 The sectional area of a solid stem bar is to be greater than rule requirements by:-

Class 1 - 30 per cent.

The connections of the shell plating to the stem bar are to be flush.

2440 Where a plate stem is fitted, the thickness of the plates below a position 750 mm (29.5 in) above the load waterline is not to be less than:-

Class 1 - 1,8 t_b

2441 Below the load waterline, plate stems should be reinforced by a centreline web - Ice Classes 1 only-and by horizontal webs. The horizontal

webs are to be spaced not more than 700 mm (27.5 in) for class 1 and 915 mm (36 in) for other classes.

Machinery requirements are listed in Section H-8 of Lloyd's Rules and Regulations for the Construction and Classification of Steel Ships.

APPENDIX VI

Total Costs of Ice Strengthened Bulk Carriers
(Exclusive of insurance, profits and contingencies)

In 1969 Dollars
Assumes 10,500 mile round trip

	65,000 DWT	150,000 DWT	250,000 DWT
Fuel Cost (1)	481,320	587,880	770,130
Crew Cost (2)	222,000	222,000	222,000
Maintenance + Repair	43,000	57,200	71,000
Lube Oil Cost	1,000	1,200	1,600
Stores Cost	50,000	50,000	50,000
Total Operating Costs	797,320	918,280	1,114,730
Amortization + Interest(8%-11 years)	1,500,000	2,200,000	3,380,000
Total Cost	2,297,320	3,118,280	4,494,730
Annual Cargo Tons (3)	619,272	1,338,561	2,236,635
Cost per ton(US $)	3.71	2.33	2.01
Cost per ton(Can $)	4.00	2.52	2.17
Cost per ton-mile (Can¢)	.076	.048	.041
Cost/short ton-mile (Can ¢)	.068	.043	.037

(1) Based on respective fuel consumption of 100, 122 and 160 long-tons per day at $14 per ton.

(2) Based on European crew of 30, includes vacation and annual home leave.

(3) Assumes 9 round trips per year.

APPENDIX VII

TOTAL COSTS OF SUBMARINE SUPERTANKERS
(exclusive of insurance, profits and contingencies)

In 1969 Dollars

Assumes 10,500 mile return trip

	150,000 DWT	200,000 DWT	250,000 DWT
Fuel	1,398,960	1,698,675	1,971,710
Crew	1,000,000	1,000,000	1,000,000
Maintenance + Repair	100,000	125,000	150,000
Stores	75,000	75,000	75,000
Miscellaneous	20,000	20,000	20,000
Total Operating Costs	2,593,960	2,918,675	3,216,710
Amortization + Interest (8% -11 years)	11,900,000	15,450,000	19,000,000
Total Annual Cost	14,493,960	18,368,675	22,216,710
Annual Cargo Tons	2,175,000	2,900,000	3,625,000
Cost/ton (US $)	6.66	6.34	6.13
Cost/ton (Can $)	7.19	6.85	6.62
Cost/ton-mile (Can ¢)	.137	.130	.126
Cost/short ton-mile (Can ¢)	.122	.116	.112

APPENDIX V111

OIL PIPELINE

Diameter	-	42 inches
Annual throughput	-	12.3 million tons
Length	-	1500 miles
Annual Ton Miles	-	18,450 million

Annual Operating Cost		Cost/ ton mile (Can ¢)
Operating cost per ton mile for oil pipeline companies presently averages 0.054¢		
The remoteness of the line would add another 25% for a total of:		0.068
Amortization and Interest		
(8%-25 years, capital cost of $375,000 per mile)		
Annual cost per mile	$35,000	
Annual cost for line	$52,500,000	0.284
Cost per ton mile		0.352

APPENDIX IX

OIL PIPELINE

Diameter	-	48 inches
Annual throughput	-	12.3 million tons
Length	-	1500 miles
Annual Ton Miles	-	18,450 million

Annual Operating Costs		Cost / ton-mile (Can ¢)
Same assumptions as in 42" line		0.068

Amortization and Interest

(8% - 25 years; capital costs of $1 million per mile)

Annual Cost per mile	$94,000	
Annual Cost for line	$141,000,000	0.765
Cost per ton mile		0.833

APPENDIX X

RAILWAY

Basis of Calculations

Length:	500 Miles
Number of Cars:	500
Capacity of Ore Car:	100 tons
Number of locomotives:	20
Time per return trip:	56 hours
Average speed:	25 m.p.h.
Return trips per year per train:	150
Annual tonnage:	150 trips x 5 trains x 10,000 tons = 7.5 million tons
Annual ton miles:	7.5 million tons x 500 miles = 3,750 million ton-miles

Assumptions

Each train is comprised of 4 locomotives and 100 cars and travels at an average speed of 25 m.p.h. Terminal time at each end of the line is estimated at 8 hours.

	Cost / ton mile (Can ¢)
Operating Cost per Car	
150 trips x 1000 miles = 150,000 car miles/ year at 2.7/cents per car mile	.0540
Fixed Maintenance Cost	
$2500 / mile / year x 500 miles =$1,250,000	.0333
Back Shopping Charge	
$500 / Mile / Year x 500 miles =$250,000	.0066

Appendix X . / .

Fuel Cost	Cost/ton mile (Can ¢)
1 cent /BHP/ hour; each diesel generates 2500 h.p.	
Based on 6000 hours operation per year	
Costs are 6000 x 2500 x 1¢ x 20 diesels = $3,000,000	0.0800
Amortization and Interest	
Cars: 15 years - 8%	0.0312
Cost per car - $20,000	
Cost per year is $2,340	
Diesels: 15 years - 8%	0.0186
Cost per diesel is $300,000	
Cost for 20 diesels is $6,000,000	
Annual amortization & interest is $700,000	
Rail Line: 30 years - 8%	0.4133
Assume cost of $350,000 / mile	
Total cost is $175,000,000	
Cost per year is $15,500,000	
Cost per ton- mile (Can ¢)	0.6370

APPENDIX X1

AIR CUSHION VEHICLE

Basis of Calculations:

Annual Utilization 2000 hours

Type Vehicle	HM2	HM4	SRN6	SRN4
Capital Cost	$200,000	$1,800,000	$350,000	$4,500,000
Spares	10,000	250,000	20,000	450,000
	$210,000	$2,050,000	$370,000	$4,950,000
10% residual	21,000	205,000	37,000	495,000
	$189,000	$1,845,000	$333,000	$4,455,000
Annual Operating Costs (excluding insurance)				
Hourly: Fuel	$14	$154	$33	$325
M &R	11	140	52	394
	$25	$294	$85	$719
Annual: Fuel M &R	$50,000	$588,000	$170,000	$1,438,000
Crew	55,000	110,000	55,000	110,000
	$105,000	$698,000	$225,000	$1,548,000
Amortization & Interest (8% - 10 years)	$28,000	$275,000	$49,000	$665,000
Total DOC	$133,000	$973,000	$274,000	$2,213,000
Indirect cost (40% DOC)	53,200	389,200	109,600	885,200
Total Costs	$186,200	$1,362,200	$383,600	$3,098,200
Capacity (tons)	5	60	3	60
Speed (mph)	35	45	65	70
Ton Miles (50% load factor)	175,000	2,700,000	195,000	4,200,000
Cost / Ton Mile (Can ¢)	$1.06	$0.50	$1.96	$0.74

APPENDIX X11

MONORAIL

Quantity:	210,000 tons per annum
Distance:	100 miles
Capacity of Car	20 tons

Ton Miles/year	21,000,000
Return trips/year	1,050
Ton Miles/car/year	2,100,000
No. of cars.	10
Average speed	50 mph.

	Cost/ton-mile (Can ¢)
Operating Costs $4,600/car/year	.22
Fixed Maintenance Costs $3,000/mile/year	1.43
Fuel Costs 2 cents/kwh; 300 KW per car	1.20
Amortization & Interest	
Foundation, supports, electrical components, rail - (20 years - 8%) Capital cost $3 million / mile Cost per mile / year = $306,000	145.50
Cars (15 years - 8%)	
Capital cost per car - $100,000 Cost per car / year = $11,700	.56
Cost per ton-mile	148.91

APPENDIX X111
OFF - HIGHWAY VEHICLE

Basis of Calculations for Tractor - Trailer Operations:

Length of ice road	300 miles
Season	3 months
Capacity	90 tons
Average speed	25 MPH
Approximate running hours	1500
Time per return trip	48 hours
RT/Season	45
Tonnage/vehicle/season	4050
Ton-miles/vehicle/season	1,215,000

Annual Operating Costs (excluding insurance)	Cost/ton mile (Can ¢)
Fuel Consumption - 8 gallons / hour Seasonal consumption = 12,000 gallons Assume cost is 25¢ / gallon	0.247
Tires 10 tires on tractor at \$200/tire 8 tires on trailer at \$500/tire Total tire cost - \$6000 Assume life of tires on ice road is 60,000 miles Since seasonal mileage is 27,000 miles; then tire replacement cost for season is: - $\frac{27,000}{60,000} \times \$6000 = \$2700$	0.222
Tire Repairs Approximately 15% of tire cost	0.033
Oil, Grease Approximately 50¢ / hour	0.062
Repairs (including parts & labour) Approximately \$6.00/ hour	0.740

Appendix X111 ./.

Amortization & Interest (8 % -five years)	**Cost / ton mile (Can ¢)**
Tractor cost - $35,000 Trailer cost - $25,000	
Assume one-half of cost absorbed by Northern operation. Annual cost is $7550	0.620
Wage & Fringe Benefits	
2 drivers at $1250 each / month	0.617
Indirect	
Approximately 40% of DOC	1.020
Ice Road	
Cost and maintenance of road is approximately $500 /mi / season or $150,000 per season	
Assume total tonnage over road during season is 20,000 tons	2.500
COST PER TON MILE (Can ¢)	6.061

APPENDIX XIV
CONVEYOR BELT

Basis of Calculations:

Length		27,500 feet
Vertical lift		130 feet
Capacity		1200 tons/hour
Belt Widths	Conventional	42 inches
	Cable	42 inches
	Steel cord	36 inches
Annual Tonnage		3,500,000
Amortization and Interest		15 years - 8%

Conveyor Belt Type	Total Annual Costs (U.S.$)	Cost/ton (U.S.¢)	Cost/ton Mile (U.S.¢)
Conventional belt conveyor	658,000	18.8	3.6
Steel cord belt conveyor	611,000	17.5	3.4
Cable belt conveyor	581,000	16.6	3.2

Relating these costs to construction in the Arctic, higher freight and labour costs must be included in the capital and operating costs. The Arctic costs per ton-mile would be in the order of:

Conveyor Belt Type	Arctic Cost per ton (Can ¢)	Arctic cost per ton mile (Can ¢)
Conventional belt conveyor	34.0	6.5
Steel cord belt conveyor	31.5	6.1
Cable belt conveyor	30.0	5.8